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With particular reference to the Dragset area

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Sammendrag

THE GEOLOGY OF THE LØKKEN AREA

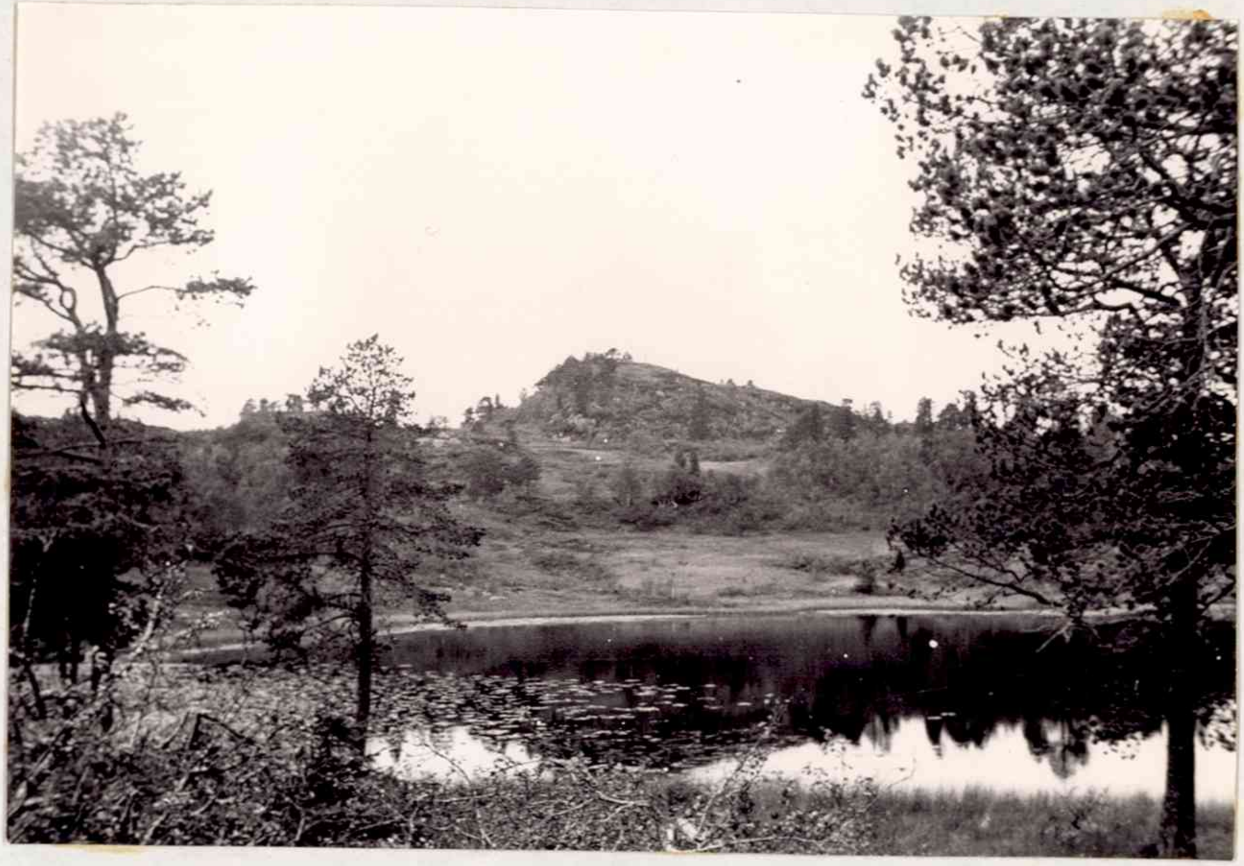
OF

CENTRAL NORWAY

WITH PARTICULAR REFERENCE TO THE DRAGSET AREA

BY

R. CHAPLOW



Frontispiece. The typical appearance of the Dragset Area.

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Acknowledgements

I should like to express my gratitude to the Orkla Grube Aktiebolag, and in particular to Messrs. Sandvick, Brondbo, Norstein and Sagvold for their help and encouragement during the period of the field investigations and afterwards.

The assistance in the field of Mr. Rutter and Prof. T. Strand is also here acknowledged.

I should also like to thank Dr. W. Skiba, of the Geology Department at Imperial College, for his supervision in all stages of this project.

Foreward

This report is based on the results of seven weeks' field work undertaken in the Lökken Area of Central Norway. The Dragset Area, that is the area to the west of the road running northwards from Storaas to Dragset Mine, was investigated in detail by the present author. However, in order to gain a general appreciation of the regional geology, and also to maintain consistency in the mapping, some time was spent in studying the geology of the surrounding areas. The areas visited included those mapped by Blake and Chadwick (1961), Rutter (1966), and May (1966). Areas occupied by rocks of the Basal Gneiss and Sparagmitian complexes were also visited to the west of Rindal.

The detailed mapping was undertaken using aerial photographs on the scale of 1:15,000, kindly loaned by Orkla Grube Aktiebolag. These photographs were also used to construct the base map for use in the final presentation of the findings of the investigations.

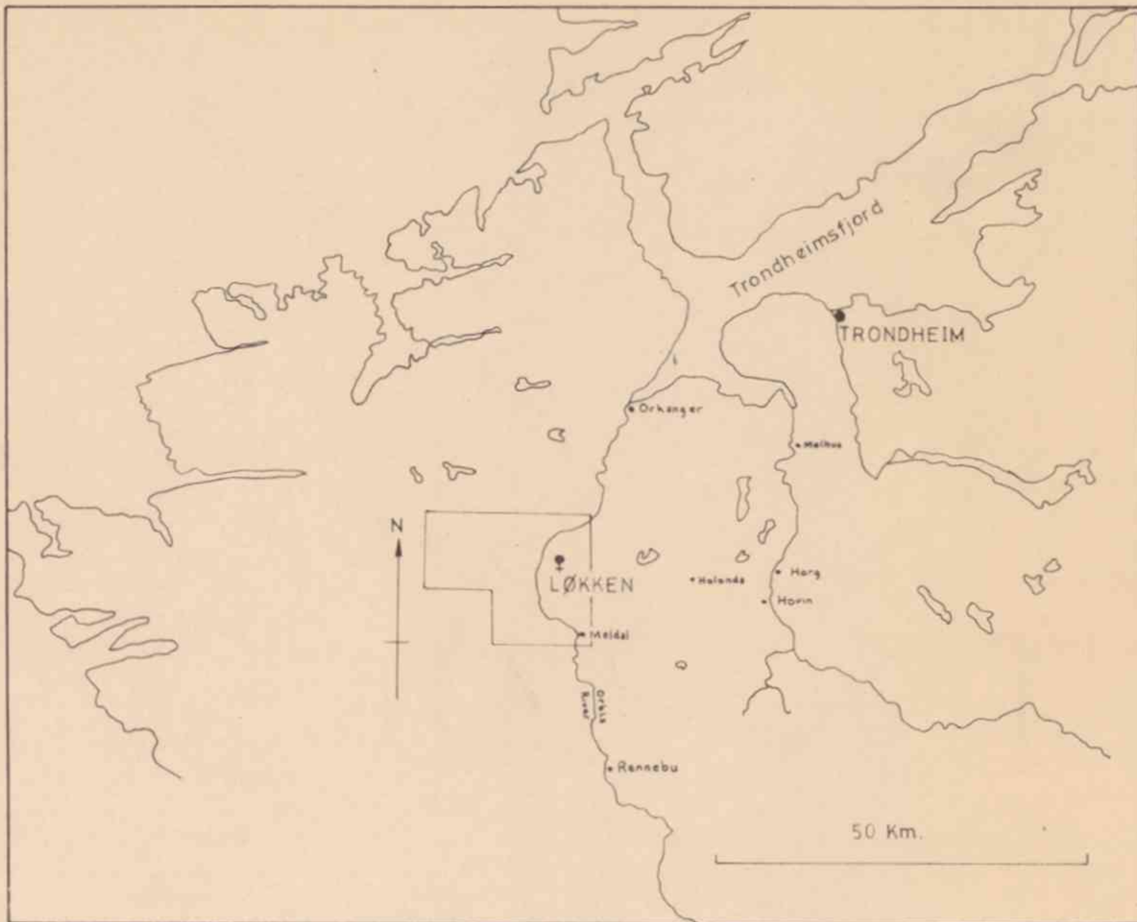
A certain amount of distortion is unavoidable in the final maps, as a result of their compilation from aerial photographs, but it is hoped to subsequently transfer the data obtained onto accurate topographical maps currently being produced in Norway.

Introduction

The village of Lökken lies some 70 Km. to the southwest of Trondheim in the county of Sor Trondelag in Central Norway, (Maps 1 and 2). The area investigated in detail by the author is situated approximately 10 Km. to the west of Lökken. Here, unlike much of the remainder of the Lökken area, the forest cover is relatively thin and the topography less severe. The topography is dominated by a series of relatively low ridges which trend parallel to the strike of the schistosity. Several much higher ridges and cliffs also occur. The latter features tend, in general, to mark major lithological boundaries.

The ridges are cross-cut by a series of north-south valleys. The majority of these constitute relatively small topographic features. However, others, such as the valley trending north-south through Bjortjern, form major topographic depressions. These are, nevertheless, not on the scale of the valleys occupied by Lökken or the Orkla River.

The vegetation in the areas where the forest is not dominant consists primarily of grasses and small bushes. In general, the rock exposure is very limited, being confined mainly to the sides of the ridges, there being no exposure in the valleys which are usually extremely marshy (see frontispiece).

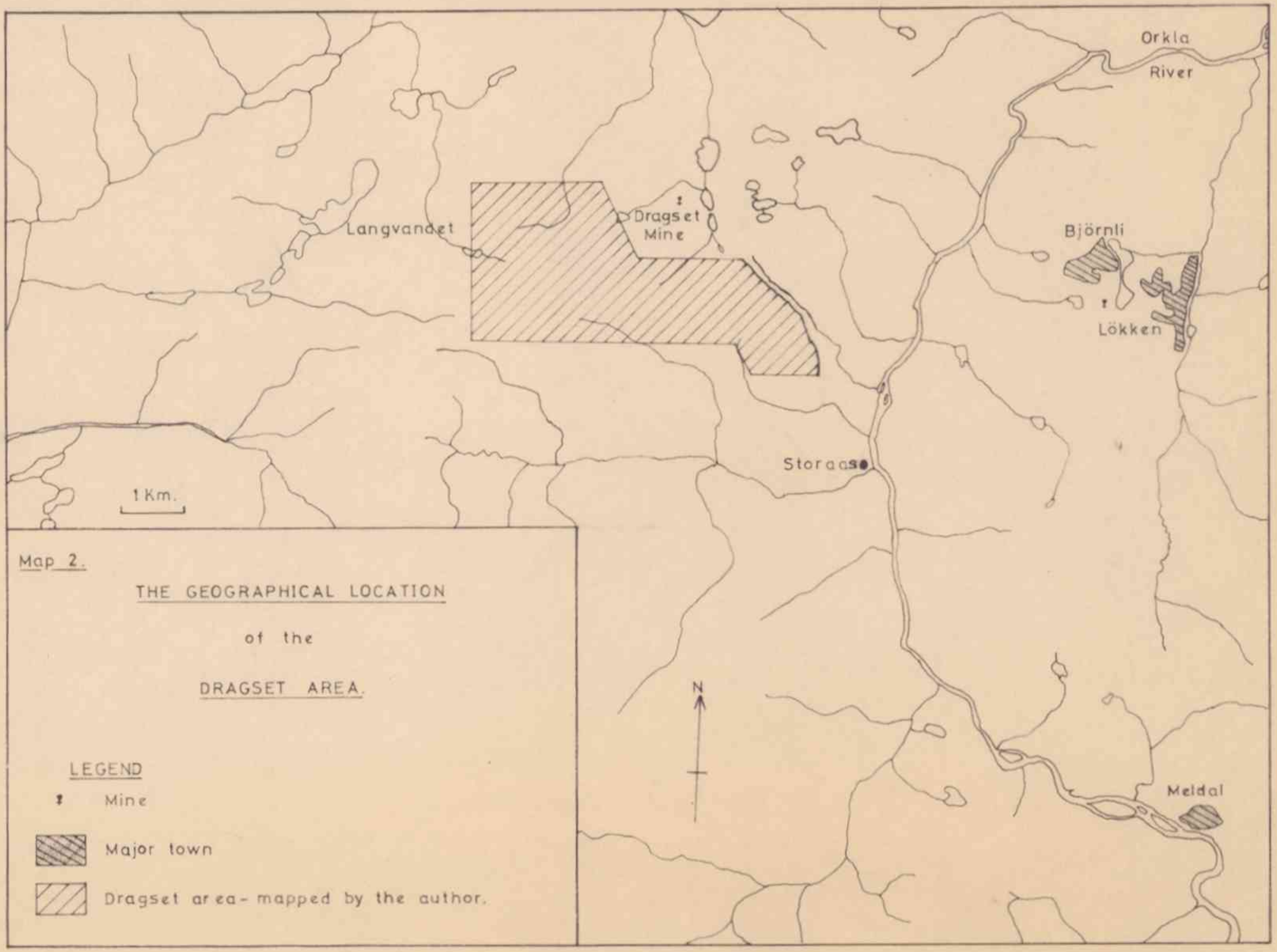


THE GEOGRAPHICAL LOCATION

of the

LØKKEN AREA

Map 1.



Orkla
River
Langvandet
Dragset
Mine
Björnli
Lökken
Storaas
1 Km.
N
Meldal
Map 2.
THE GEOGRAPHICAL LOCATION
of the
DRAGSET AREA.
LEGEND
Mine
Major town
Dragset area - mapped by the author.

Statement of the Problem

In the summer of 1966 a team of students from Imperial College began a detailed geological investigation of the area around the Løkken Pyrite Mine. This investigation was carried out at the request of P. Sandvick, chief mine engineer with Orkla Grube Aktiebolag. The team was supervised by Dr. W. Skiba. The problem of elucidating the geology of the area was approached from three different viewpoints.

Mr. E. H. Rutter concentrated on the structural geology of the area, Mr. J. May studied the petrology and geochemistry of the rocks, and Mr. I. Kershaw worked in the immediate vicinity of the mine, concentrating his attention on the economic aspects of the problem.

Following this preliminary survey, the investigations were continued, by a further group of students, during the summer of 1967. The present author extended the area mapped in detail, working to the west of Dragset Mine. His responsibilities also involved the collection of structural orientation data for subsequent analysis, along with the collection of rock specimens for use in the extension of the study of the geochemistry of the suite of greenschist facies rocks found in this area.

History of Previous Research

The Lökken Area forms the westward continuation of the Fjeldheim-Gaasbaken area which was mapped in 1960-61 by Messrs. Chadwick, Blake, Rowling and Beswick. The area consists basically of a broad structural depression in which metamorphosed Cambro-Silurian rocks have been preserved.

H. Carstens (1952) mapped the entire area covered by this investigation, but only on a scale of 1:50,000. He subdivided the rocks according to the classical stratigraphic succession established in the region through the work of various Norwegian geologists. Three main groups were recognised:

Hovin Group	Lower and Middle Ordovician	Shales, sandstones and limestones
Stören Group	Upper Cambrian and Lower	Metamorphosed basic volcanics
Röros Group	Cambrian and Eocambrian?	Mica schists

Subsequently, Bugge (1954), in a general summary of the geology of the Norwegian Caledonides, suggested that in certain areas the Röros Group schists were to be regarded as the stratigraphical equivalents of the Hovin Group.

During the summers of 1959-60 the Dragset area was mapped by a Norwegian student under the direction of

Professor T. Strand. Unfortunately there is no record of this work except for a map on the scale of 1:10,000 showing the geographical distribution of the main lithologies.

Orkla Grube Aktiebolag have, in the past twenty-five years, conducted numerous aeromagnetic and electromagnetic geophysical surveys over a large part of the Lökken area. Some of the anomalies discovered have been interpreted in terms of known geological features but in general the use of geophysical methods seems to be limited.

The work carried out in 1966 considerably increased the knowledge of the area's geology. A scheme of structural history was outlined by Rutter. He emphasised, nevertheless, that because of the large size of the major structures, there was a great need to extend the investigations over a much larger area in the immediate vicinity of Lökken. Various specific problems remained unsolved, including the establishment of the axial direction of the f_1 folds.

The geochemistry of the rocks was investigated by May. He demonstrated that not all the rocks were typically spilitic. Nevertheless it was decided that on the basis of the combination of mineralogy, mode of occurrence, modal composition and chemistry of the rocks that the spilitekeratophyre nomenclature would be adopted. This practice has been followed by the present author.

Wolff (1967) stated that he was convinced that Bugge was correct in his suggestion that the Röros Group rocks were, in the Meråker area to the east, equivalent to the Hovin-Holonda rocks of the eastern Trondheim Region. This statement was in direct conflict with Strand (1960) who regarded the "Röros" schists as older than the Störon Group rocks which they structurally underlie.

In a recent paper Dietrich (1967) describes a suite of ophiolites of Upper Jurassic age from the Alps. All the rocks have been transformed into true greenschists during the Alpine metamorphism. The similarity between the rocks described by Dietrich and those observed in the Lökken area is truly remarkable. A further feature of his work is that it has disclosed the presence of hyaloclastites which are again remarkably similar to rocks found on a preliminary survey to the east of Lökken. The mode of deformation observed by Dietrich is also directly comparable with that found in the Lökken area.

The Geology of Central Norway

Central Norway may be divided, essentially, into four distinct geological regions (see Map B), namely:

(i) Basal Gneisses
(ii) Rocks of the Nappe Region
(iii) Sparagmite Region
(iv) Trondheim Region

(i) Basal Gneisses

Large areas along the western coast of Norway from south of Bergen to about latitude 65°N are occupied by gneisses. Petrographically the gneisses are of the same type as the Archean gneisses in the south-eastern part of the country, and like these they form the basement of the Cambro-Silurian rocks which overlie them. A fundamental difference between the south-east and north-west areas lies in the fact that while there is a distinct and sharply marked unconformity above the Archean gneisses in the south-east, there is an equally perfect conformity between the Cambro-Silurian sediments and the underlying gneisses in the north-west area. In fact, in many areas no sharp contacts can be found between the sediments and the gneisses.

Oftedahl, (1964) in his paper on "The nature of the basement contact", is of the opinion that where there appears to be perfect conformity between the basal gneisses and the Cambro-Silurian rocks then these latter deposits are in fact concordant. Thus, if this is so, then it would require that the Pre-Cambrian rocks were essentially flat-lying and unfolded at the beginning of the Cambrian and Eo-Cambrian sedimentation.

The data from the relevant areas is somewhat limited, however, and Oftedahl advances his theory on the basis that no unconformities have as yet been recognised.

(ii) Rocks of the Nappe Region

Several areas have been recognised in the central part of southern Norway where large areas of rock appear to have been thrust over younger sediments as huge nappes.

Such thrust sheets were first recognised after it was seen that the metamorphic grade increased upwards. At first, this was interpreted as being due to contact metamorphic effects caused by igneous rocks intruded into the upper part of the sedimentary pile, and later removed by erosion. Subsequently the concept of nappe structures was postulated.

In general this theory was based upon, firstly, the presence of well marked thrust planes with mechanical contacts and mylonitisation, and secondly, on the basis of the marked differences in the petrographic constitution or sedimentary facies and/or metamorphic grade of the rocks above and below the thrust planes.

(iii) Sparagmite Region

The term "Sparagmite" was instituted by Esmark (1829) for slightly metamorphosed feldsparrich sandstones which occur in the Østerdalen district. Kjerulf took a broader look at the regions where these sparagmites occur. Here, besides the feldspathic sandstones, he recognised quarzites, conglomerates, shales and carbonate rocks, although it was found that the areas were devoid of igneous rocks.

Along their western boundary the sparagmites dip beneath normally overlying Cambro-Ordivician sediments, whilst along their north-western boundary they are overlain by the Cambro-Ordivician sediments of the Trondheim Region, which are most probably in an allochtonous position above them. The south and south-eastern margins of the area are occupied by the nappes of "quartz-sandstones" which rest in an authochtonous position on the peneplanated Archean surface. Thrusts of up to 35 Km. in length are known to exist in this area.

The base of the type section of the Sparagmites is nowhere exposed, therefore their tectonic position is doubtful. Holtedahl, and later Skjeseth (1954), assumed that the sparagmite deposits of the complete succession were laid down in depressed or down-faulted basins in the Archean basement. Hence they were, tectonically, in a protected position and therefore they have been but little moved from their original position, although quite extensive folding has occured within the basin.

The dominant rocks of the northern part of the Sparagmite

Region are light sparagmites; metamorphosed, light coloured rocks, the fine grained and schistose varieties of which have the character of flagstones.

The allochtonous position of the large masses of light sparagmites is testified to in certain areas. Thus in the windows of Archean rocks in the northern part of the Sparagmite Region they rest with tectonic contacts upon the "basal tillites" and other authochtonous deposits of the younger part of the Sparagmitian Complex.

(iv) Trondheim Region

This region consists of a broad axial depression in which metamorphosed Cambro-Silurian sediments have been preserved from erosion. The narrow south-western part of the region is connected with the Nappe Region, whilst at the western side the Cambro-Silurian sediments overlie the basal gneisses. However, in most areas they are separated from the basal gneisses by a band of sparagmitian rocks of variable thickness. At the south-eastern side of the Trondheim Region the sediments overlie, once again, the rocks of the Sparagmite Complex.

The dominant rocks of this region are argillites in various stages of metamorphism ranging from rocks showing only mechanical metamorphism through those regionally metamorphosed in the chlorite grade, up to those showing assemblages of minerals characteristic of the garnet grade.

It is within this region that the area studied by the author is situated.

Approach to the Field Mapping

Within the area investigated by the present author, hereafter refered to as the Dragset Area, (Maps A, 2), all the rocks have been subjected to Greenschist facies metamorphism, chiefly in the chlorite grade. As a result of this, all the rocks, which originally consisted mainly of basic volcanics and sediments, have become remarkably similar in appearance. In order to maintain continuity, therefore, in the mapping of these rocks, some considerable time was spent initially in gaining a general appreciation of the geology of the surrounding area. The assistance of Messrs. Rutter and Sagvold, and of Professor T. Strand, was invaluable in this respect.

The detailed mapping was carried out directly onto aerial photographs on the scale of 1:15,000. These proved to be ideal for orientation in the field.

The extremely poor exposure in the area, coupled with the lack of distinctiveness between adjacent rock types, made it necessary to develop special mapping techniques. The author eventually decided that it was most practical first to locate a lithological boundary by a traverse perpendicular to the strike, and having once located such a boundary to trace it for as far as practical along the strike. These strike traverses were subsequently linked together by the occasional dip traverse. The dip traverses were of very limited value since, because of the poor exposure and the great similarity between adjacent rock types, boundaries were often missed.

The rock types identified in the field were as follows:

(a) Fine grained basic metavolcanics

These rocks are green in colour, fine grained and basic in composition (Plate 1). They typically show pillow structures, although some massive varieties were observed. The rocks show varying amounts of strain ranging from those showing pillows that are virtually undeformed (Plate 2), through to those rocks in which a schistosity is carried in the matrix of the rock around the somewhat flattened pillows. Finally there are those rocks which, whilst still recognisable as original pillow lavas, carry a penetrative schistosity undeflected by the individual pillows. In general, it is noticed that the amount of deformation suffered by these rocks increases from south to north.

Where large exposures occur, especially in cliff sections, individual flow units may sometimes be recognised. However, a lack of exposure generally prevents these being traced for any distance.

(b) Albite Dolerite

A distinctive band of a medium grained basic rock was traced in an east-west direction for a considerable distance across the area. The rock consisted of albite, epidote, chlorite and a fibrous amphibole, and ranged in texture from being massive to a rock carrying a penetrative schistosity. An intrusive origin was assumed and hence this rock type was given the name of Albite Dolerite.

Apart from the main band of this rock type several smaller occurrences were also noted.

(c) Conglomerate

A discontinuous band of a deformed conglomerate occurs within the Dragset area. It consists of fragments of fine grained basic metavolcanics set in a fine grained schistose matrix of similar mineralogical composition (Plate 3).

(d) Chlorite Schist

The chlorite schists encountered seem to consist entirely of meta-sediments. In many places original sedimentary structures may still be recognised, particularly graded bedding.

Occurrences of chloritoid schists have also been noted.

(e) Basic Dyke Rock

A dark coloured basic dyke was traced for several kilometres in an east-west direction across the area. Only one major dyke was located, but many other smaller ones of a similar nature are known to exist within the Lökken Area.

(f) Fragmentary Acid Rock

Associated with the major basic dyke and conglomerate in certain areas was a medium grained, very light coloured acid rock. This consisted of small, discrete grains of quartz and feldspar set in a fine grained and frequently schistose matrix.

(g) Mica Schist

To the north of the Dragset Area and in the Rorvandet road section, the chlorite schists pass into schists containing muscovite and biotite. A rather sharp boundary exists between the chlorite and mica schists.

(h) Jasper

Throughout the area small lenses of red jasper occur. Blue quartz also occurs and in two cases, namely at Dambuslettet and Fjellslettet, it is in direct association with thin horizons of massive pyrite.

Plate 1. Typical appearance of the fine-grained basic metavolcanics on a weathered surface.

Plate 2. Undeformed pillows at the classical locality to the south-east of Dragsetmoen.

Plate 3. Deformed conglomerate. Typical appearance of the weathered surfaces of the conglomerates in the Dragset Area.

Stratigraphy of the Lökken Area

Two distinct lithological groups are represented in the area of the investigations:

(i) The Storen Group

This group consists, almost entirely, of spilitic lavas and tuffaceous sediments with minor quantities of acid volcanic products and cherts. In places the rocks of this group have been intruded by a number of gabbro masses.

(ii) The Hovin Group

The Hovin Group of rocks is made up primarily of sandstones and shales. Some intercalations of basic volcanic material occur near the base of the succession. A coarse polygenous breccia-conglomerate locally marks the base of this group. The conglomerate contains fragments of rock characteristic of the Stören Group and hence the Hovin Group rocks are regarded as being stratigraphically younger than the Stören Group.

In the northern part of the Lökken Area occurs a sequence of biotite- and almandine garnet-mica schists. These structurally underlie the sandstones and shales of the Hovin Group and they have, in the past, been regarded as comprising a third lithological group in the area, the Röros Group. This group of rocks is structurally the lowest in the area and, until recently, it has also been assumed to be stratigraphically the oldest. Thus the metamorphic grade boundaries were assumed to be also the stratigraphic boundaries.

Bugge (1954), in a general summary of the geology of the Norwegian Caledonides, suggested that the Röros Group schists are, in certain areas, to be regarded as the stratigraphical equivalents of the Hovin Group of rocks.

Detailed mapping of the sedimentary structures preserved in the sandstones and shales of the Hovin Group to the north of Lökken, principally along the road section from Lökken to Svorkmo, has demonstrated that the rocks young consistently northwards. There is no sign of any tectonic break and hence it thus appears that the rocks attributed to the Röros Group are, at least in the Lökken Area, younger than the rocks of the Hovin Group.

The rocks in the Lökken Area were deformed and metamorphosed in the Greenschist facies of regional metamorphism during the Caledonian Orogeny. Considerable variation in metamorphic grade and amount of deformation is observed across the area.

Metamorphism

(a) Regional Metamorphism

All the rocks in the Lökken Area have been subjected to metamorphism during the Caledonian Orogeny. The grade of metamorphism is entirely of greenschist facies in the area studied, ranging from chlorite- up to garnet grade in the far north of the area. In the Dragset area itself, only the chlorite and biotite grades are represented.

The greenschist facies represents the lower temperature part of the Barrovian type facies series, that is a relatively high pressure series. It can easily be distinguished from the higher temperature almandine-amphibolite facies when the following critical minerals, characteristic solely of the greenschist facies, are developed; namely chlorite, stilpnomelane, pyrophyllite and chloritoid. Zoisite and epidote are not restricted solely to the greenschist facies; however, the assemblage zoisite/epidote + albite does charactise it.

The plagioclase feldspar is entirely albite, having an An. content of less than 7% throughout, more basic plagioclases being unstable in the Barrovian type greenschist facies.

Three sub-facies within the greenschist facies have been recognised. They are:

(i) Quartz-albite-muscovite-chlorite sub-facies, corresponding to the chlorite-zone of the petrologists in Scotland.

(ii) Quartz-albite-epidote-biotite sub-facies, which represents the biotite-zone.

(iii) Quartz-albite-epidote-almandine sub-facies, corresponding to the lower temperature part of the garnet zone as well as to the epidote-amphibolite facies of Eskola.

(i) Quartz-Albite-Muscovite-Chlorite Sub-facies

Most of the rocks in the Dragset area have been metamorphosed in this sub-facies. The mineral stilpnomelane is restricted to this sub-facies and is developed in those rocks of suitable chemical composition. For this mineral to be developed, the original rock must have been rich in iron and at the same time impoverished in magnesium and aluminium.

Thus, when the amount of ferrous iron present is not essentially greater as compared to that of magnesium, only chlorite is generated. On the other hand, if sufficient amount of aluminium is present along with ferrous iron (more aluminium than can be taken up in muscovite, paragonite, feldspar and chlorite), then the aluminium rich iron-aluminium-silicate phase chloritoid comes into existence in lieu of the aluminium poor stilpnomelane. Zen (1960) has pointed out that stilpnomelane and chloritoid are not found to occur together, much rather they exclude each other. The mutual incompatibility is however not dictated by any particular set of physical conditions like temperature or pressure. This is solely the result of a "chemical control".

Winkler (1965) states that the mineral paragenesis characteristic of original gabbroic rocks consists of albite + epidote + chlorite + actinolite + sphene $\pm$ stilpnomelane $\pm$ quartz.

(ii) Quartz-Albite-Epidote-Biotite Sub-facies

To the north of Dragset and Lökken the grade of metamorphism reaches biotite grade. However, it must be pointed out that not all the rocks metamorphosed in this sub-facies do in fact contain biotite, but only those with the appropriate chemical composition.

In this sub-facies, original gabbroic rocks develop a mineral assemblage consisting of chlorite + actinolite + epidote + albite + sphene $\pm$ quartz $\pm$ biotite. Stilpnomelane is not stable in this sub-facies.

(iii) Quartz-Albite-Epidote-Almandine Sub-facies

To the north of the area shown on Map A, almandine garnets begin to make their appearance in the rocks and the tremolite/actinolite is replaced by a green pleochroic amphibole which seems to be hornblende.

This hornblende is the stable phase but the mineral is also developed in the lowest sub-facies of the greenschist facies. Here the hornblende is metastable, and it would appear that it has been unstable from the moment of its first appearance. According to Ostwald's Law, such phases tend to crystallise in preference to truly stable phases when their appearance involves minimal disturbance of the internal structure of the reacting system. It is by this process that the hornblende is generated as a metastable phase in the albite-muscovite-chlorite sub-facies.

(b) Contact Metamorphism

There appears to be no evidence of contact metamorphism of the country rocks around either the basic dykes or the albite dolerite intrusions. Rutter also reports that there is no evidence of contact metamorphism around the gabbro intrusions where they certainly would be expected. This would seem to suggest that the gabbros were intruded either before or during the episode of regional metamorphism which would then cause all evidence of contact metamorphism to be obliterated.

(c) Origin of the Albite in the Basic Metavolcanics

The plagioclase feldspar present in the basic lavas in the Dragset area is entirely albite, having an An. content of less than 7%. This albite may have been developed from originally more basic plagioclase during the regional metamorphism according to the reaction:

plagioclase $\longrightarrow$ albite + epidote

On the other hand, it may represent a primary magmatic mineral as has been often suggested in the past, or finally it may be a secondary product due to soda metasomatism. Turner and Verhoogen (1952) discuss the feasibility of these various alternative modes of formation, (pp. 266).

In the Dragset area, the albite appears to be entirely secondary after more basic plagioclase and in this area there appears to be no evidence to suggest a magmatic origin for the albite.

As yet no evidence has been gained in the Lökken Area to suggest whether the observed mineral assemblages are entirely metamorphic in origin or whether they were a product of metasomatic alteration and that the mineral assemblage thus produced was stable in the greenschist facies of regional metamorphism.

Description of the Detailed Geology of the Area

The Stören Group

The basic metavolcanics of the Lökken Area, which constitute the Stören Group, form the core of a synformal structure, referred to as the Lökken Synform.

Much of this thick sequence of rocks consists of spilitic pillow lavas. Massive lavas, basic tuffaceous beds, conglomerates and lenses of red jasper occur in minor quantities as intercalations within the sequence. Thin bands of pyritous black shales, locally called "vasskis", are also quite common, but since they are thin they are only discovered where favourable exposures occur.

Several thin bands of massive pyrite occur within the basic volcanic products in the Dragset area. Such bands occur at Dambuslettet and Fjellsettet. In both cases, the massive pyrite is in direct association with blue quartz and vasskis. However, at other localities it is found that vasskis may occur alone, that, is without the associated massive pyrite, but the converse does not apply. The main pyrite ore-bodies, which occur at Lökken, Dragset and Hoidal, are all associated with vasskis.

The area mapped by Rutter (1966) is far more densely forested than the Dragset area, and is therefore not so well exposed. Rutter reports that the intercalations of the various other rock types within the basic metavolcanics are "neither laterally continuous nor very thick". He adds that it has hence proved impossible to stratigraphically subdivide the fine grained rocks within the Stören Group. In contrast to this, the present author has, in the Dragset area, traced a virtually continuous band of conglomerate around the hinge of the f_2 synform. Bands of albite dolerite have also been traced for some considerable distance. In addition, various distinctive bands of spilitic lavas have been recognised. Such bands include rocks containing virtually no epidote, and others exhibiting no pillow structures but having an extremely high density. Such bands may prove capable of being traced if extremely detailed mapping of the area is undertaken. Such a project would require close study of literally every exposure and as such would be extremely slow and tedious.

Before such a project as this was undertaken, it would be necessary to evolve various reliable criteria for distinguishing between the closely similar rock types. It would also be necessary to establish how much variation in these characteristics occured within individual flows. If appreciable variation does occur, then, on the grounds of poor exposure, it will be impossible to map out individual flows.

It is already known that individual flow units may exhibit pillow structures at their base and yet be massive at their top, presumably representing eruption of the lava into extremely shallow water. Hence, the presence or absence of pillows is not a reliable criterion by which to identify individual flow units. The current studies on the geochemical and petrographic variation within single flows, being undertaken by Dr. W. Skiba, may determine the feasibility of the individual lava flows being mapped out and a stratigraphic subdivision of the Stören Group being evolved.

In certain local areas, it has already been possible to delineate individual flows from topographic features. This is, however, impossible on a regional scale. Topography is, nevertheless, a very useful tool in the mapping of certain major lithological boundaries. Thus the southern boundary of the spilitic lavas is marked by an extremely prominent cliff, and the major band of albite dolerite follows a well developed topographic depression with a prominent cliff on much of its northern side (Plate 4).

Care must be exercised, however, in the interpretation of the structural significance of the bands of albite dolerite. This, unlike the conglomerate bands, probably does not represent a stratigraphic horizon since it is extremely likely that this rock is in fact intrusive in origin, and hence it is to be expected that this rock type will show cross-cutting relationships.

All the rocks in the Stören Group within the Lökken Area have been metamorphosed in the Greenschist facies of regional metamorphism. Nevertheless, where the rocks are only slightly deformed, primary structures and textures are preserved. The pillows within the lavas are perhaps the best preserved of all the primary structures in the area.

Where the pillows are virtually undeformed - the type locality for this occurs about 1 Km. south of the road bridge over the Orkla River at Dragsetmoen, on the eastern side of the river - the local younging direction of the beds can be determined, with a good degree of certainty, from the shape of the pillows (Plate 5). However, as the pillows become progressively more deformed, they gradually lose their original shape and begin to take up a shape and orientation determined by the principal stresses acting upon them. By this process, the pillows are gradually extended in an approximately east-west direction, and are flattened in the plane of the schistosity.

The pillows frequently show an internal concentric zoning. The outer rims of the pillows consist of a thin zone, up to ½ cm. in thickness, of chlorite. Within this is an epidote rich zone. This may attain a thickness of up to 2 cm. and within it epidote infilled vesicles may sometimes be distinguished. The core of the pillows typically consists of a fine grained intergrowth of actinolite and tremolite needles, albite, chlorite and epidote (Plate 6). Where the rocks are quite intensely deformed, then in many cases the only way of recognising original pillow lavas is by the presence of the infilled vesicles (Plate 7).

The proportions of the various minerals present in the spilitic lavas varies quite extensively throughout the area. This variation tends to produce corresponding variations in the colour of the rocks. In general, large amounts of albite and epidote produce a light green colouration; whilst chlorite, when abundant, gives the rock a much darker colour. It is because of this factor that the rocks cannot be divided into individual flow units on the basis of colour alone, since any slight differentiation within a flow may produce quite significant variations of colour. These colour variations can frequently be observed on the scale of a single exposure.

Within the Stören Group there is a limited occurence of acid volcanic rocks. In the Dragset area, these are totally absent, except for a thin band of a fragmentary acid rock. However, in other parts of the Lökken Area rocks do occur in several geographically separate localities.

Rutter has described these acid metavolcanics as quartz-keratophyres, following the description of the soda-rich basic rocks as spilites. He has mapped two areas of acid rocks in the Lökken Area and a third is believed to occur to the west of the Dragset area. It may be significant that all these reported occurences of acid rocks lie very close to the axis of the f_2 Lökken Synform.

The acid rocks most commonly form lenticular intercalations within the basic metavolcanics. They vary in thickness from 1-20 m. Fine banding and fragmentary structures are quite commonly observed in the thinner members, which are generally non-porphyritic.

The acid fragmentary rock which occurs in the Dragset area is a very light coloured rock, which in parts is extremely schistose. It consists of fresh, angular grains of quartz and anorthoclase set in an altered ground mass consisting of albite and epidote, pseudomorphed after plagioclase (Plate 8). The epidote is very fine grained and it forms a reticulate pattern within the albite. Occasionally, ghosts of the original plagioclase can be seen, but these are rare and more usually the ground mass is uniform in texture. This rock probably represents a tuffaceous deposit.

A somewhat discontinuous band of conglomerate occurs within the spilitic lavas in the Dragset area, although several similar bands have been mapped elsewhere. These consist of fragments of the fine grained spilitic lavas set in a fine grained matrix of similar mineralogical composition. Much secondary calcite occurs in this rock type as well as in most of the other rock types in the region.

In the band of conglomerate mapped by the author, the fragments were made up entirely of the basic metavolcanics. The fragments ranged in size quite extensively, reaching a maximum diameter of 8 ins. The matrix and fragments hardly differed at all in mineralogy, and yet the fragments tended to weather less readily than the matrix. As a result of this the fragments stood out in relief from the weathered surface, thus giving such surfaces a typical conglomeratic appearance (Plate 9). This differential weathering probably reflects the fact that the matrix carries a schistosity produced during the deformation of the rock, whereas the fragments have remained massive. Hence, the matrix was left more susceptible to weathering than the fragments.

One of the most distinctive rock types in the area studied was the medium grained basic rock which formed a continuous mappable horizon trending for approximately 10 Km. in an east-west direction. This rock, with virtually the same mineralogy as the spilitic lavas, has been referred to as albite dolerite. Apart from the main band, several subsidiary occurrences were noted.

The rock is made up of clusters of a green, pleochroic amphibole set in a mass of chiefly euhedral epidote, albite laths and interstitial chlorite. The green pleochroic amphibole and the stilpnomelane, which is also present in minor quantities, appear to cross-cut the other minerals and thus these probably represent secondary, metamorphic minerals (Plate 10). Leucoxene is also present, and from the ghost cleavage preserved within it it would appear to be secondary after pyroxene.

The stilpnomelane suggests that the rocks have been metamorphosed in the chlorite grade of regional metamorphism. However, at such a grade of metamorphism the appearance of the green pleochroic amphibole, which seems to be hornblende, would not be expected. Turner and Verhoogen record similar occurrences of hornblende and state that, "it is by no means uncommon to find scattered grains of metastable green hornblende pseudomorphed after igneous augite or brown hornblende. Appearances of hornblende as a transitory phase involves relatively slight changes in previously existing space lattices of pyroxenes". Whether or not the widespread occurrence of hornblende in the albite dolerite is analogous with the "scattered grains" of Turner and Verhoogen is a matter of personal opinion. However, if it is not so, some other explanation must be found for the association of these supposedly incompatible minerals.

The albite dolerite is thought to represent a feeder dyke for the spilitic lavas of the Stören Group. The contact of the albite dolerite with the basic lavas is exposed at several localities, and in most cases the contacts are here seen to be sharp (Plate 11). There is no evidence of either chilling of the albite dolerite or contact metamorphism of the country rock at the locality illustrated. However, elsewhere the dolerite is noticed to become finer grained and more variable near to its margins. The boundaries are sharp in general, but gradational contacts do occur. It may be that in these cases it is the chilling of the albite dolerite near its margins that is causing the dyke rock to take on the appearance of the spilitic lavas. It is reasonable to assume that certain other contact phenomenon may have been partially removed by the regional metamorphism.

The conclusive piece of evidence to suggest that the albite dolerite represents a feeder dyke rests on the occurrence, about 2 Km. to the north-east of Storaas, of a rock that appears to be a true volcanic agglomerate. This is completely enclosed by the albite dolerite, and it appears to be completely undeformed. It consists of thoroughly angular fragments of basic lava. All the fragments make direct physical contact with their immediate neighbours.

A further significant feature is that the width of the albite dolerite dyke seems to be directly proportional to the width of the outcrop of the spilitic lavas of the Lökken Synform. Thus, it seems probable that the quantity of lava erupted was directly proportional to the dimensions of the feeder dyke.

The Stören Group rocks also contain large masses of cupiferous pyrite. The largest of these outcrops is at Lökken, where it is currently being mined by Orkla Grube Aktiebolag. Small ore-bodies also occur at Dragset and Hoidal, both of which were formerly worked. Neither of these mines are in current production. Pyrite is a universal accessory mineral in all the rocks in the area.

In addition to the previously mentioned ore-bodies, thinner bands of massive pyrite occur in the Lökken Area. Two such bands were located by the present author in the Dragset area, and both of these appeared to have been worked at the surface to a minor degree at some time during the past. Bands of about 1 ft. in thickness were studied at Dambuslettet and Fjelslettet. The author feels that it is significant that in both these cases the massive pyrite was associated with silica and vasskis. In these and all other reported cases, the massive pyrite is found to occur together with quartz and vasskis; however, both these latter rock types are known to occur extensively alone.

At Dambuslettet, the massive pyrite is also associated with a band of massive magnetite. Here also, a thrust can be recognised, and within the associated fracture zone fragments of jasper have been cemented together by crystalline magnetite.

The jasper lenses are extremely common throughout the region. They are chiefly confined to the Stören Group rocks; however, some also occur within the chlorite schists, especially on the junction between the metavolcanics and the metasediments. The jasper has an intense red colouration, even on weathered surfaces, and is therefore easily recognised. At a locality of about 3 Km. to the north of Storaas, the jasper is being worked commercially. The use of the jasper as a source of pure silica for smelting purposes has been investigated, but most of the local occurrences tend to contain too much phosphorus to make such a proposition feasible.

The individual grains of quartz within the silica varieties encountered frequently show undulose extinction, indicative of strain. There also seems to be a suggestion of the grains showing a preferred orientation but as yet no detailed study of the petrofabrics has been made.

An extensive programme of rock sampling was undertaken within the Stören Group to provide samples for geochemical investigation. Several problems are to be investigated, namely:

(i) Variations in chemistry within individual pillows,

(ii) Variations of chemistry between pillows of comparable size and amount of deformation, but from different positions in an individual flow,

(iii) Variations in the chemistry of pillows of differing sizes from comparable positions in an individual flow,

(iv) Variations in the chemistry of pillows which have suffered different amounts of straining.

These investigations are to be carried out chiefly on the basis of soda content determinations, although several specimens will have a full analysis carried out upon them in order to try and establish a relationship between bulk geochemistry and soda content of the rocks.

Plate 4. Cliff marking the junction between the albite dolerite and the fine-grained basic metavolcanics, the latter rock type forming the cliff.

Plate 5. Undeformed pillows, the shape of which show that these beds are the right way up.

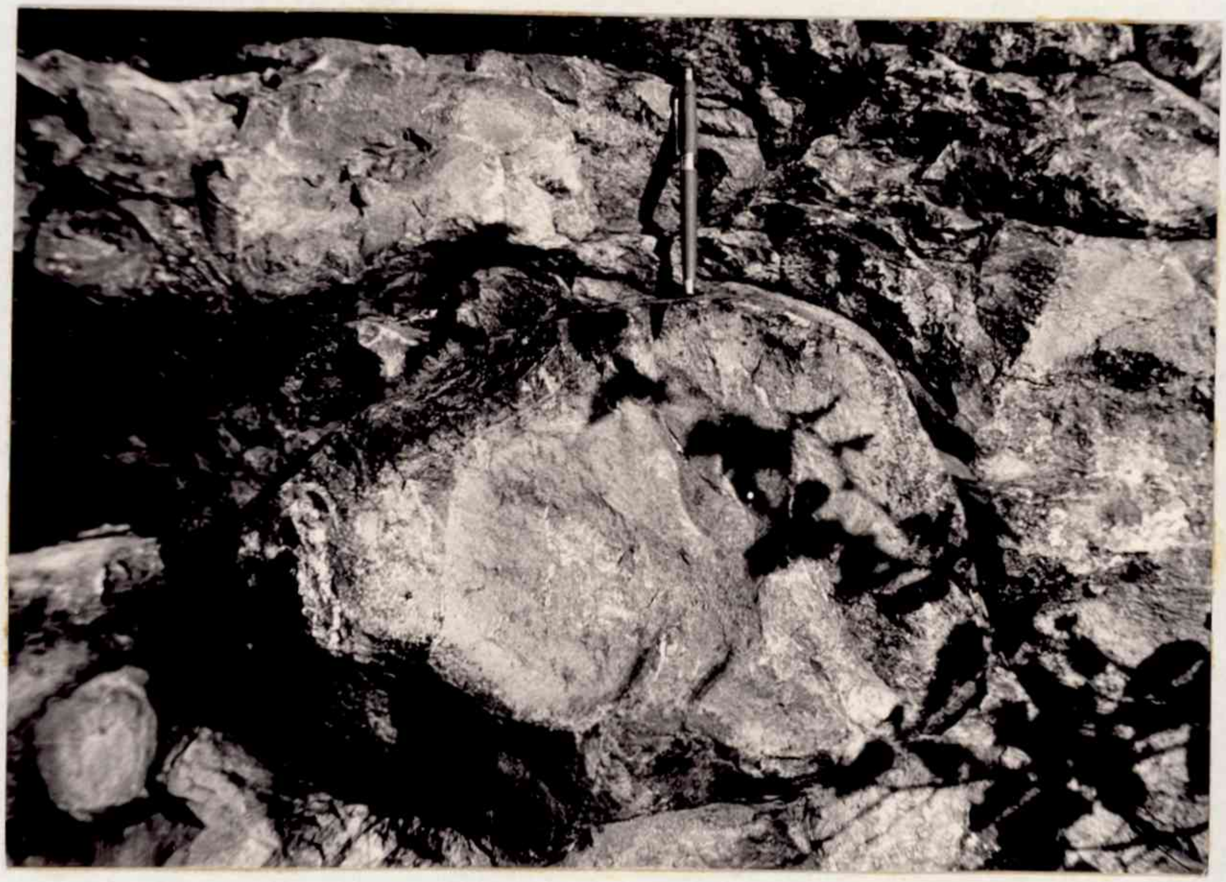


Plate 6. Undeformed pillows showing the concentric mineral zoning and infilled vesicles.

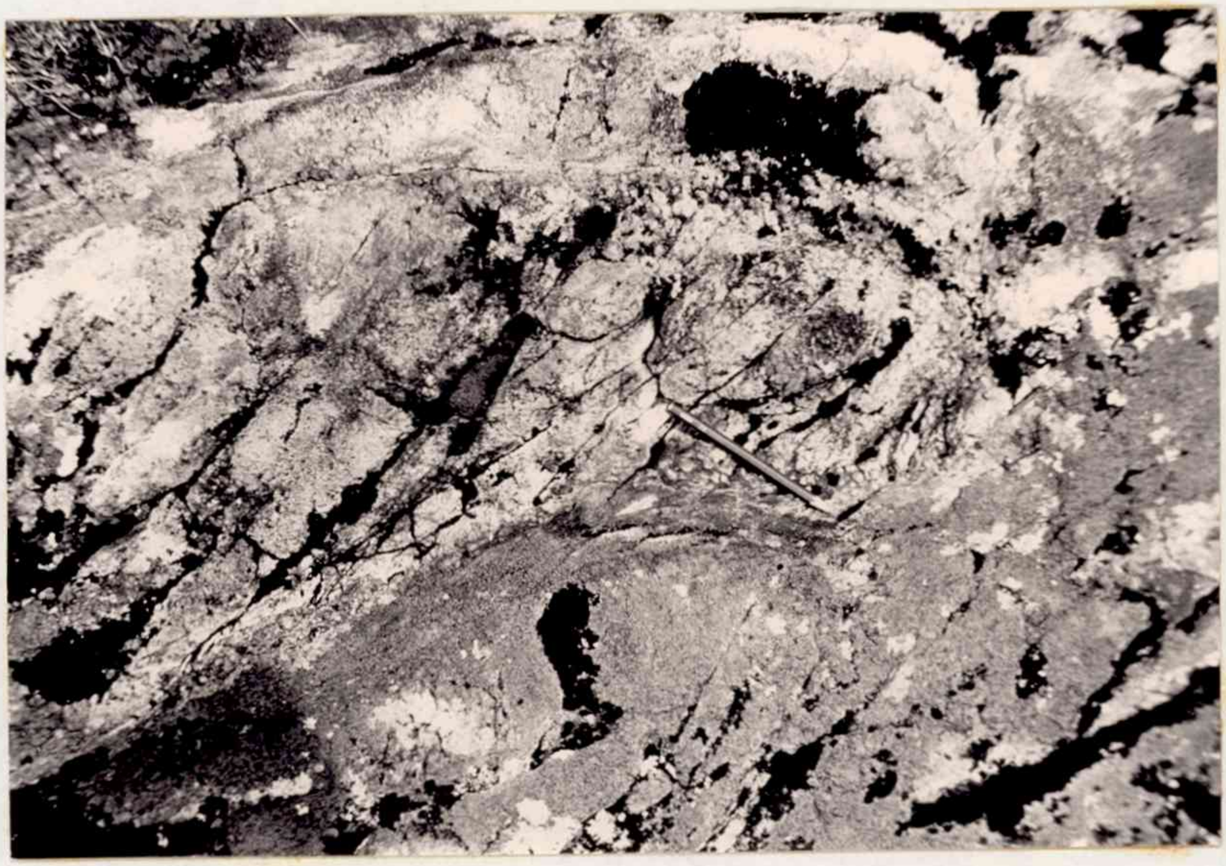


Plate 7. Deformed pillow. The presence of the pillow is shown solely by the mineral zonation.

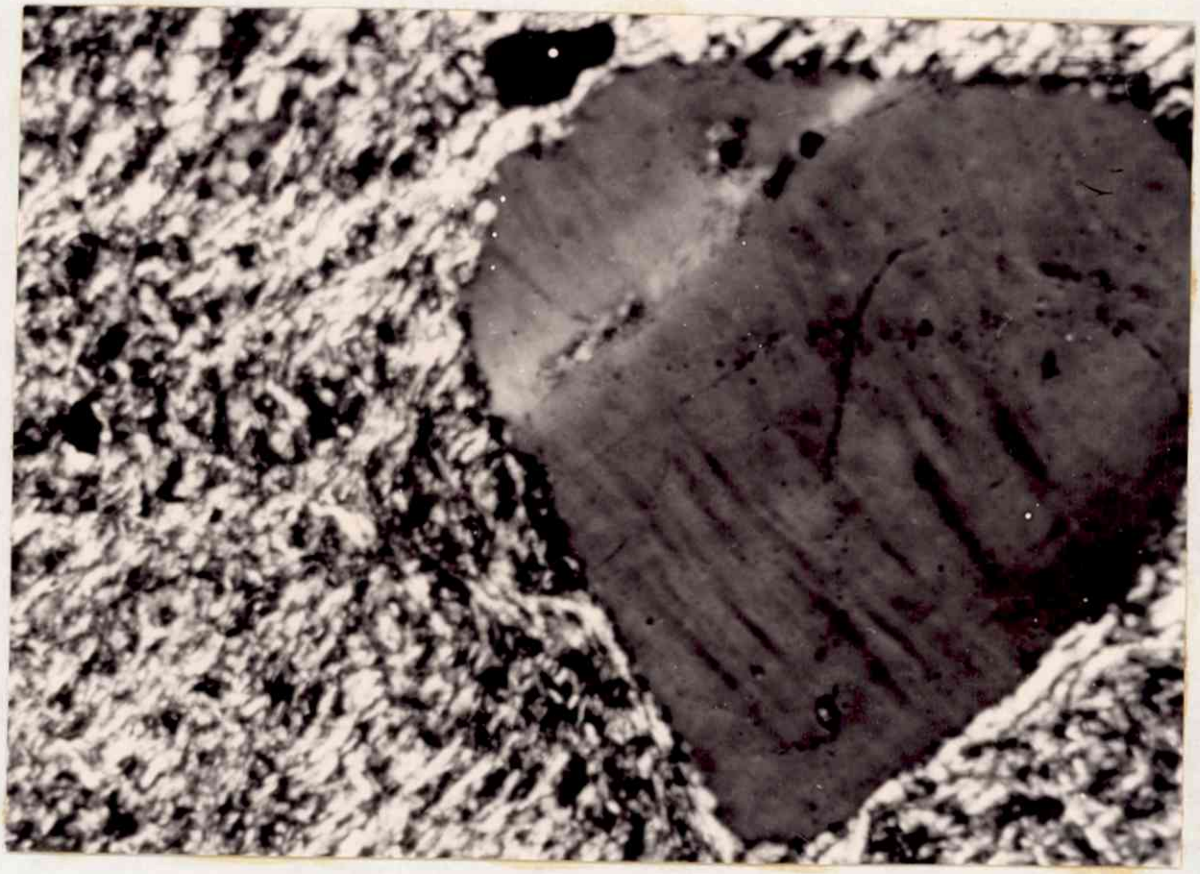


Plate 8. Photomicrograph of the fragmentary acid rock. An anorthoclase grain is set in a fine-grained, reticulate groundmass of albite and epidote.

Plate 9. Deformed conglomerate.

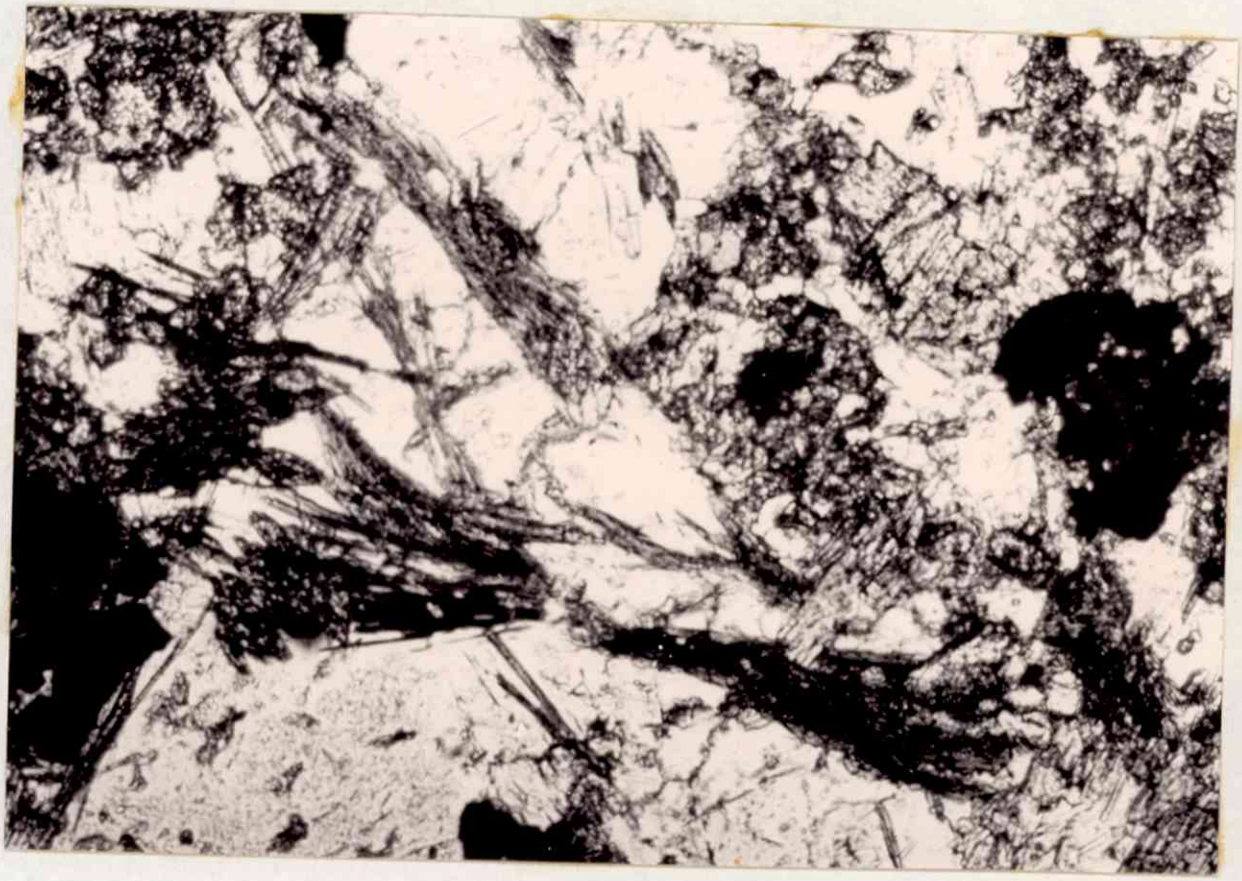


Plate 10. Photomicrograph of a medium grained basic metavolcanic rock showing the secondary, metamorphic stilpnomelane and hornblende.

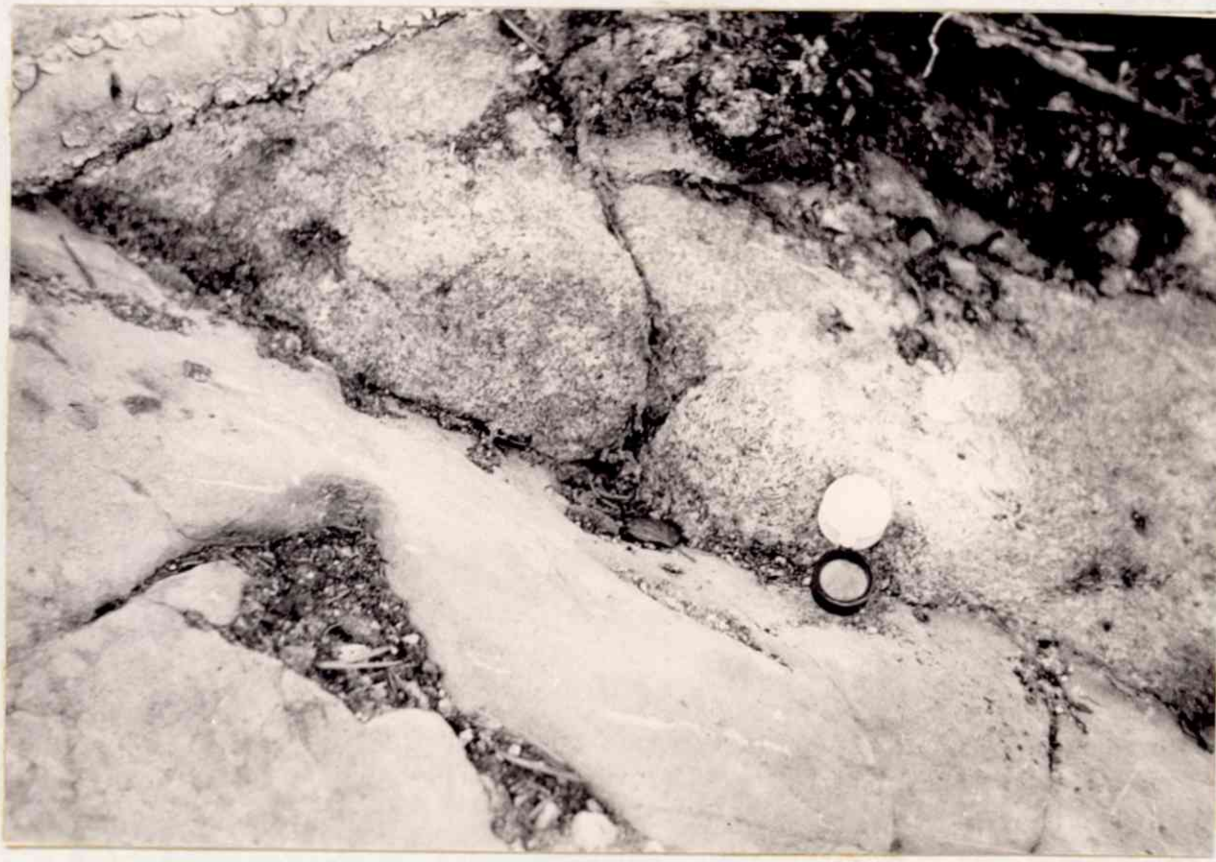


Plate 11. Sharp junction between the albite dolerite and the fine grained spilitic lavas.

The Hovin Group

The Hovin Group of rocks consists almost entirely of sediments, many of which are tuffaceous in nature. The rocks in the Lökken Area may be correlated directly with those of the neighbouring Fjeldheim region to the east. This enables the unfossiliferous rocks in the Lökken Area to be assigned an Arenigian age following the identification of Arenigian graptolites in rocks, at a stratigraphically equivalent level, near Fjeldheim (Blake, 1962).

The lowest member of the Hovin Group is a breccia-conglomerate which immediately overlies the basic lavas of the Stören Group. The conglomerate is highly variable in lateral extent and thickness. It appears to have been derived by rapid erosion of Stören Group lavas following a period of rapid uplift. Petrographically, the conglomerate is entirely comparable to the laterally equivalent Fjeldheim Conglomerate which was described by Chadwick et al., (1964).

In the Lökken Area, the breccia-conglomerate is overlain by a series of sandstones and shales, which are often banded so that the angular divergence between the bedding and the cleavage may be discerned. Beneath the bridge over the river at Storaas, two folds can be recognised in the bedded Hovin Group sediments using the easily interpreted bedding-cleavage relationships.

Occasionally, a coarsening of grain sige produces intercalations of conglomerate within the series. Most of the grains of the sandstones are lithic, and they are very poorly sorted. These rocks were clearly laid down in an unstable environment as evidenced by the common occurrence of graded bedding in the sandstone members.

The sandstone and shale series outcrops on both the northern and southern flanks of the Lökken Synform. In the south, these rocks are metamorphosed to chlorite grade and they are almost undeformed. Hence, primary sedimentary structures are well preserved. To the south of Dragset the highest part of the sequence becomes a hematite rich shale. On the northern flank of the Lökken Synform the metamorphic grade is high chlorite, and the deformation is much stronger. The shaly components of the series are reconstituted to chlorite schists. Metamorphic segregation has taken place giving rise to bands alternately rich in chlorite, calcite and epidote. In contrast, the more massive sandstone bands still exhibit clearly defined graded bedding. Chloritoid schists were found to occur at two localities.

To the north, the succession passes stratigraphically upwards into quartz-albite-mica schists, the transition being gradational. The higher grade of metamorphism experienced by these mica schists has resulted in the destruction of some of the primary structures. However, from those still recognisable these schists would also appear to represent original sediments, somewhat poorer in basic volcanic products than the older, adjacent sediments.

The metamorphic grade reaches biotite sub-facies in the outcrop of these schists, and even further north almandine garnets begin to appear in the rocks.

It would appear that the metamorphic isograds cut obliquely across the f_1 fold structures from the way in which the metamorphic grade increases in the direction of stratigraphic younging.

Intrusive Rocks

In the Lökken Area the Stören Group rocks are intruded by several large gabbro masses. It would appear that the intrusion of these masses occurred at an early stage in the orogenic activity and was possibly contemperaneous with the eruption of the basic volcanics. No gabbro masses occur in the Dragset area.

The gabbros have been metamorphosed with the country rocks. This has resulted in the obliteration of any contact effects which would normally be expected around such masses; however, the primary gabbroic texture has been preserved in the larger masses, but pseudomorphed by new minerals.

The smaller gabbro masses have been deformed and have locally developed a schistosity. In contrast, the larger masses do not appear to have responded to the tectonic stresses and thus they show no internal deformation.

The gabbros appear to have originally consisted of calcic plagioclase and augite pyroxene. Traces of primary pyroxene remain in some parts of the gabbro, but in most cases it has been completely pseudomorphed by a mixture of tremolite and a green pleochronic amphibole, probably hornblende. The calcic plagioclase has been replaced by an intergrowth of albite and epidote.

The gabbro masses, where they are sufficiently well exposed, show extensive banding. This primary banding is particularly well seen within the Lökken Mine and is produced by alternations of felsic and mafic rich layers. Such banding is found in all the gabbro masses, particularly near to the margins.

Rutter (1966) has reported the existence of granophyric zones around some of the margins of the metagabbro masses.

A very distinctive porphyritic rock is developed to a limited extent in the Lökken Area. This is rather similar to the Holonda Porphyrite described by Chadwick et al. (1964), and which occurs very extensively several kilometres to the east of Lökken.

In the Lökken Area, small stock-like masses and cross-cutting dykes occur together with lenticular bodies, these occurrences being entirely confined within the metavolcanics of the Stören Group. In contrast, in the Gaasbakken area the Holonda Porphyrites are most extensively developed in the lower part of the Hovin Group. A controversy exists as to whether these rocks are intrusive or whether they represent lava flows. From the evidence, it would seem that they are either intrusive or else their development spans a considerable range of time.

Basic dykes are quite extensively developed throughout the Lökken Area, within the Stören Group. Only one such dyke proved to be sufficiently extensive to be traced for any distance. This occurred some 3 Km. to the north of Storaas, and it was traced for approximately 3 Km. in a westerly direction.

The rock was rather dark in colour, and fine grained. Mineralogically, it consisted of laths of albite, up to 2 mm. in length, along with anhedral grains of epidote set in a fine grained groundmass of albite, epidote and chlorite. Metamorphic stilpnomelane was also present, showing its typical intense pleochroism and bow-tie mode of occurrence.

The albite appeared to be relatively fresh, and it did not contain the fine grained epidote inclusions so often present in secondary albite after plagioclase. However, the laths of albite do contain numerous colourless inclusions which show high refractive indices. Some of these appear to be of tremolite, but others seem to be of plagioclase. Thus, in this rock type also the albite appears to be secondary after plagioclase.

A major dyke of albite dolerite, along with several smaller masses, occur within the Stören Group rocks. This rock appears to be intrusive, but since the intrusion seems to have been contemperaneous with the eruption of the spilitic lavas the description of the dolerite is dealt with as part of the Stören Group.

Structural Geology

At least two stages of deformation are recognisable in the Lökken Area, the two being capable of recognition according to the association of structures that they have produced. These structures are indicative of the style of deformation. A third stage of deformation may be inferred, but this had only very minor effects on the overall structure of the area.

(a) The earlier folds, f_1.

The most obvious indicator of the early deformation is the presence of a penetrative schistosity. This is seen to be parallel to the axial surfaces of small folds in rocks which exhibit primary banding particularly well. Such folds are only seen on the scale of a single exposure where the bedding is thin, (10 cm. or less) as in the sandstones and shales, or where they affect quartz veins. Small scale fold of f_1 are never seen in the thick metavolcanics of the Stören Group.

Within the chlorite and biotite-mica schists exposed along the Rorvandet road section, there is abundant evidence of f_1 folding preserved in the form of folded quartz veins. These veins represent a form of primary banding, since it would appear that they were formed prior to the earliest f_1 deformation. The f_1 schistosity can be seen to be parallel to the axial planes of these folds (fig. 1).

On this road section also, bedded sandstones and shales were exposed, and within these minor f_1 folds could be detected in the thin sandstone horizons. The symmetry of these folds could be determined, but the limited occurrences of such folds made it virtually impossible to map out the major structures from these relationships as determined from this preliminary survey.

Folds of f_1 age can also be inferred from mapped bedding-cleavage and way-up criteria in bedded horizons. Graded bedding relationships are especially useful in this respect. It is also possible to map out a set of flat lying, nappe-like overfolds of f_1 age that have been refolded by the f_2 movements (see Block Diagram). Much of the evidence for the existence of these major f_1 structures was obtained from the study of the road section between Lökken and Svorkmo. Furthermore, detailed studies of the Rorvandet road section may disclose the presence of similar major f_1 structures.

A tight f_1 syncline has been recognised in the Hovin Group sediments near Storaas. This syncline proved to be antiformal; this conflicts with the findings of Chadwick et al. (1964) along the eastern continuation of the same structure.

Only the f_1 phase of folding seems to have produced a significant amount of internal deformation within the rocks. Deformed particles are seen to be flattened in the plane of the f_1 schistosity; and the shape of such features as pillow structures, gas vesicles, spherulites and conglomerate pebbles can be used as potential indicators of the amount of internal strain suffered by the rocks. However, it is extremely unlikely that these features were originally spherical and it is to be rather expected that these non-spherical particles originally possessed some kind of fabric. Nevertheless, where the rocks have been highly strained the long axes of these particles may be used to indicate the direction of maximum finite extension in the rocks. Such measurements of the f_1 stretch direction indicate that it is approximately parallel to the axial direction of the f_1 folds and from bedding-cleavage intersection lineations in the bedded sedimentary rocks.

The rocks most frequently do not show a pronounced mineral lineation. There are exceptions and here the lineation, as before, is parallel to the f_1 fold axes. More commonly however the fibrous and acicular minerals, particularly tremolite, lie in the place of the f_1 schistosity and show a random orientation within this plane, thus giving rise to the characteristic "Garben Schifer" texture.

Great care is required when taking orientation measurements on the pillow lava or conglomerate outcrops. First it is necessary to carefully distinguish primary layering from schistosity. Undeformed pillow lavas tend to be slightly flattened as a result of the superincumbent load during the cooling after eruption. This gives rise to a measureable "primary layering" of the flow. During deformation this is obscured and replaced by a flattening of the pillows in the plane of the schistosity (Plate 12) which may or may not coincide with the primary layering.

The earliest stage in the deformation of the pillows seems to be a rotation and interlocking of the pillows. This results in the formation of slickensides on the chloritic surfaces of the pillows. Further strain must be taken up by the internal deformation of the pillows, thus the whole pillow now begins to change its shape, as also do the internal structures such as the vesicles. Eventually a schistosity develops. At first this is carried solely by the matrix around the pillows and thus the schistosity is deflected around the pillows. At higher strains the pillows themselves take on a penetrative schistosity.

All these stages are represented in the pillow lavas of the Løkken Area but it is found that, in general, few of the pillows show no straining. In fact it is found that it is only in the south of the area near Storaas that undeformed pillows are found and it can be seen that the amount of straining increases towards the north.

A second difficulty arises within the collection of orientation data within the Stören Group of rocks. It is found that the massive lavas can be cut by two joint sets which break up the rock into rhombic joint blocks. These may very easily be mistaken for pillows, and often the only feature which distinguishes these joint blocks from pillows is the absence of the concentric zoning normally associated with the actual pillows.

The conglomerates found in the Lökken Area are also frequently deformed and the measurement of the long axes of the pebbles again showed a parallelism with the axial direction of the f_1 folds (Plates 3 and 9). The basal conglomerate of the Hovin Group contains, in addition to the more usual volcanic fragments, pebbles of jasper. These, unlike the volcanics, which deformed almost homogeneously with the matrix to produce good planar and linear fabrics, tend to have resisted deformation. Consequently, the schistosity in the matrix is seen to be deflected around these rigid fragments. Under conditions of less straining, the schistosity is deflected around the spilite fragments also. In such cases the schistosity is carried solely by the matrix.

(b) <u>The later folds</u>, f_2

Unlike the f_1 folds, the f_2 folds do not appear to have produced any strong internal deformation of the rocks. There is no associated metamorphism. The large scale flexure of the Lökken synform (a synformal anticline), is the most important f_2 structure. To the north of this is a complimentary antiform which is not so well defined.

The orientation of the schistosity planes (fig. 2) show that the Lökken Synform is an open fold with an apical angle of about 85°. It has essentially planar limbs and a sharp hinge. A structure which appears to be this f_2 hinge is exposed within the Dragset area and here the hinge can be seen to be quite sharp.

The geographical distribution of the dip values of the f_1 schistosity surfaces indicates that second order minor flexures of the order of 100 m. wave length occur in the more gently dipping parts of the f_2 major structures, for example, on the southern flank areas of the Lökken Synform.

In the more schistose rocks a linear structure produced by the crenulation of chlorite and mica flakes is consistently developed (Plate 13). This linear structure appears to be coaxial with the local plunge direction of the major folds (fig. 3) (Plate 14). Other crenulations occur in the schists, notably kink bands, but their orientation is less systematic and their significance is not understood.

In the flatter parts of the limbs of the complimentary antiform to the north of the Lökken Synform, a good crenulation cleavage is observed. This intersects the f_1 schistosity to form an f_2 lineation. This cleavage is almost vertical, strikes east-west and approximates to the axial surface of the f_2 folds. Small scale minor folds, of the

f_1 schistosity, with a wave length of less than 1 m., are also quite common in the thinly laminated schists (Plates 15, 16, fig. 9). No minor folds are found in the massive basic metavolcanics of the Stören Group.

An f_2 cleavage can be seen in the folded schists at Ostli on the Rorvandet road section (Plate 16). The schists, which still display a primary sedimentary banding, have been folded by the f_1 movements and a schistosity has been developed which is here parallel to the primary banding. This indicates that this exposure lies on the limb of an isoclinal fold. The beds have then subsequently been deformed by the f_2 movements. During this folding an f_2 cleavage developed which is parallel to the axial planes of these f_2 folds.

When the orientation data from the measurements of f_2 crenulations is analysed in sub-areas it is seen that the plunge of the Lökken Synform varies in an east-west direction. This feature is displayed by analysing the f_2 crenulation data obtained from the Dragset area and from the Rorvandet road section (fig. 3). A third minor stage of folding may be inferred from this variation of plunge.

This supposed f_3 deformation is shown solely by the variation in the plunge of the f_2 folds. This may be interpreted as being caused by a series of minor buckles having north-south trending axes. On the other hand, when it is considered that the f_2 deformations were in fact produced by a buckling process, then this slight variation in plunge could be interpreted as being due to anti-clastic bending (fig. 7). This would then be a product solely of the f_2 movements and thus there would be no need to postulate the presence of any f_3 movements, for which there is no other evidence.

The massive pyrite ore-bodies tend to occur along a line parallel to the f_1 linear structures, that is, along the line connecting Dragset, Løkken and Hoidal mines. This line is slightly oblique to the hinge line of the f_2 Løkken Synform. The ore-bodies themselves are elongate in an east-west direction and tend to be flattened in the plane of the primary layering. It is probable that the marked east-west elongation is not a consequence of tectonic strain alone; it may reflect a surface feature present at the time of formation of the ore-bodies, for example, an east-west elongate trough. This statement assumes a sedimentary origin for the ore-bodies, this being the subject of much discussion. The f_1 stretching may, nevertheless, be the cause of the pinch and swell nature of the ore-bodies along their axes.

It is clear from the asymmetry of the Løkken Synform that considerable variations in the thickness of the Støren

Group volcanic pile exists within the area. The thickness of the pillow lavas in the steeply dipping northern limb of the synform is considerably less than in the more gently dipping southern limb. This can be seen from a critical examination of the geometry of the fold. It is suggested therefore that the metavolcanics thin rapidly northwards and less rapidly westwards, and this has led to a well defined axial surface trace of the synform very close to the northern contact between the metavolcanics and the structurally underlying Hovin Group metasediments.

(c) The Late f_2 Thrusts

The f_2 folds appear to have formed by a buckling process, in a less ductile environment than the f_1 folds. A late stage in the development of these f_2 folds was the formation of thrust faults which appear to have allowed relief of material from the cores of these structures. Field evidence, in the form of drag folds, suggests that some of these thrusts have moved from north to south and others from south to north. It is possible that opposite senses of movement may exist on either side of some of the thrust planes in the area.

This phenomenon of movements in opposite senses on a single thrust plane can be seen on the scale of a single exposure in a road side quarry to the south of Svorkmo on the road to Dragsetmoen.

The most extensive known thrust plane in the area is the one which occurs in the proximity of the Lökken ore-body. This thrust, which dips gently westwards, intersects the mine workings at various levels. Low angle thrusts are observed at a number of localities within the basic metavolcanics (Plate 17), but poor exposure makes it impossible to trace these for any distance.

A thrust plane is exposed about 1 Km. to the south of Dambuslettet, on the northern junction of the albite dolerite with the spilitic lavas. Here the thrust plane is composite and encloses within itself lenses of spilitic rock. Directly beneath the major line of dislocation a very schistose rock occurs which appears to contain chloritoid. Only one other occurrence of this mineral was noted within the Lökken Area and this was in the metasediments to the north of Lökken alongside the road to Svorkmo.

At Dambuslettet a thrust is exposed. Where this cuts a jasper lens the originally massive rock has been fragmented and has then subsequently been re-cemented together by coarsely crystalline magnetite.

(d) Faulting and Jointing

The area is cut by a number of north-south trending faults. These are relatively easily detected since they cut across the strike of the rocks, and are frequently marked by topographic depressions (Plate 18 and 19).

Occasionally mappable horizons can be seen to have been displaced by faults. However, many more faults than are shown on the map probably exist, but their recognition is prevented by poor exposure.

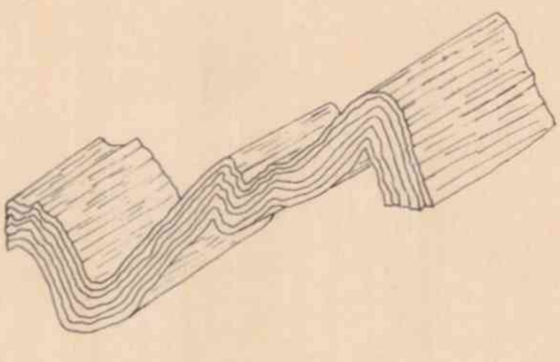
Localities do exist where the actual fault surfaces are exposed, but these are rare and more often the fracture zone is not exposed, and in such cases the fault must be postulated on the basis of the mapped relationship between adjacent rock types.

In some cases it is difficult to decide, because of poor exposure, whether a horizon of rock is naturally discontinuous or whether a continuous band formerly existed, but has been subsequently broken up by faulting. Such is the case with the conglomerate bands in the Dragset area. In several cases the conglomerate forms a distinct ridge which can easily be traced along strike. These ridges then come to abrupt ends and invariably no trace can be found of the rock type within the area of flat, marshy ground into which the ridge should supposedly pass. In certain circumstances this phenomenon has been interpreted by the author as being caused by faulting displacing the horizons. Thus when the band of albite dolerite is traced along strike, it is found that whilst in general the outcrop of the dolerite is marked by a topographic depression, in rare cases this same rock type forms a distinctive ridge.

The rocks are extensively jointed but it is really only possible to recognise one systematic joint set. This is the set of cross-joints (Plate 20), which is oriented perpendicular to the local plunge direction of the f_2 fold structures (fig. 4). The other joints appear to be fairly random in their orientation, although some suggestion of the existence of a longitudinal set is obtained from the stereographic projection of the poles to the joint surfaces (fig. 5).

Fig. 1.

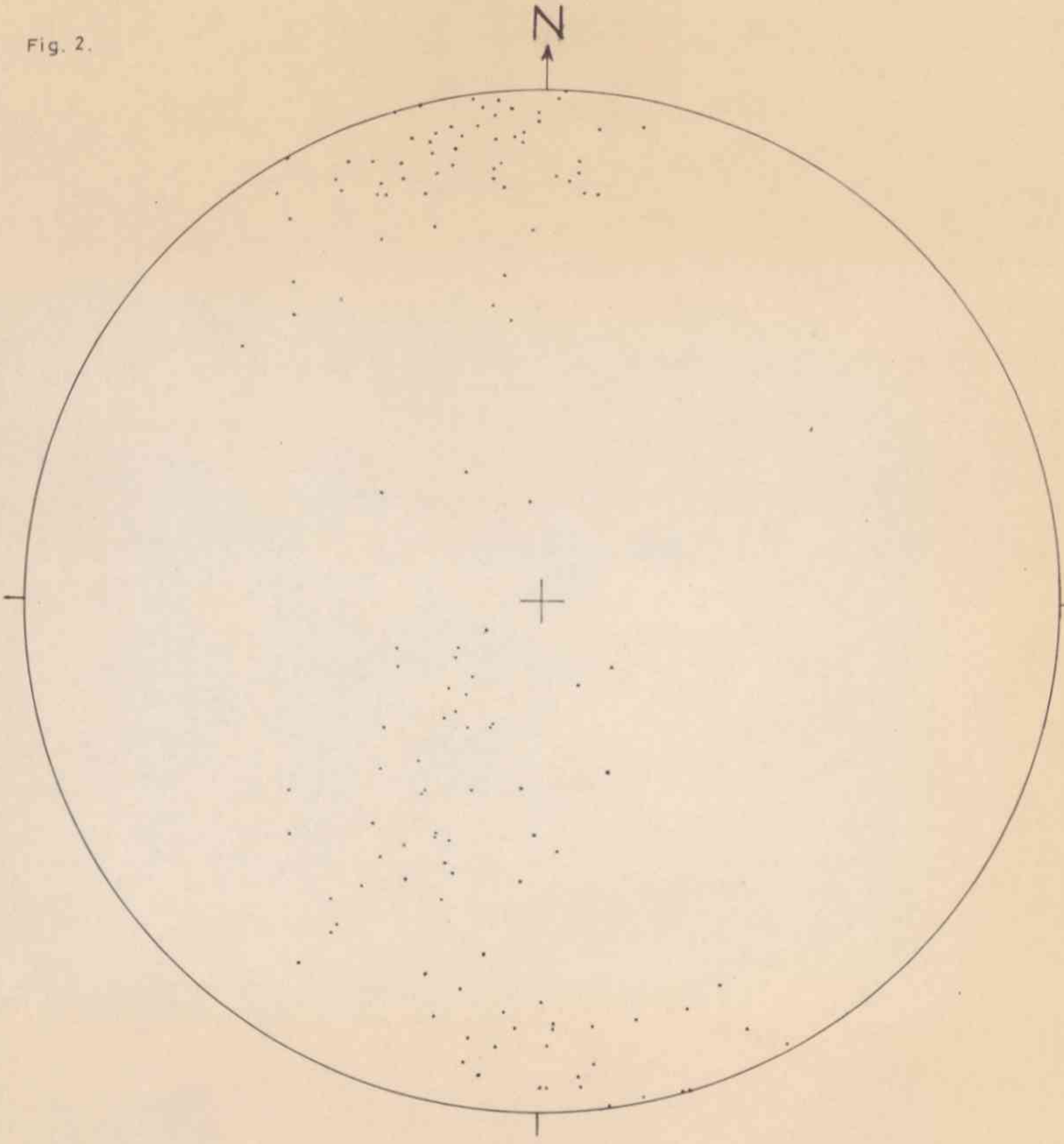
f, Fold in a quartz vein.



f_2 Crenulations.

Plate 12. Slightly deformed pillows that have been flattened in the plane of the schistosity.

Fig. 2.



POLES TO SCHISTOSITY SURFACES. (Projected from lower hemisphere.)

133 Readings.

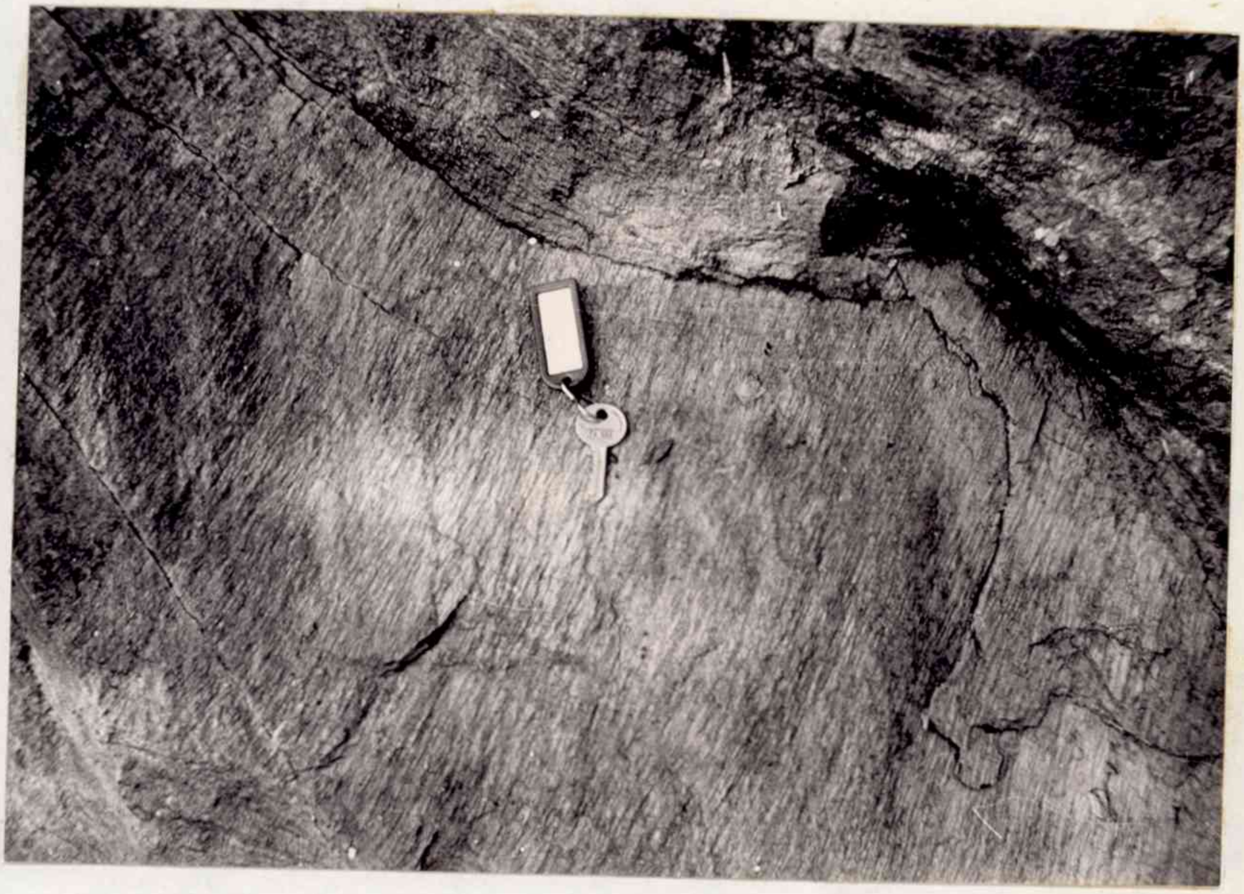
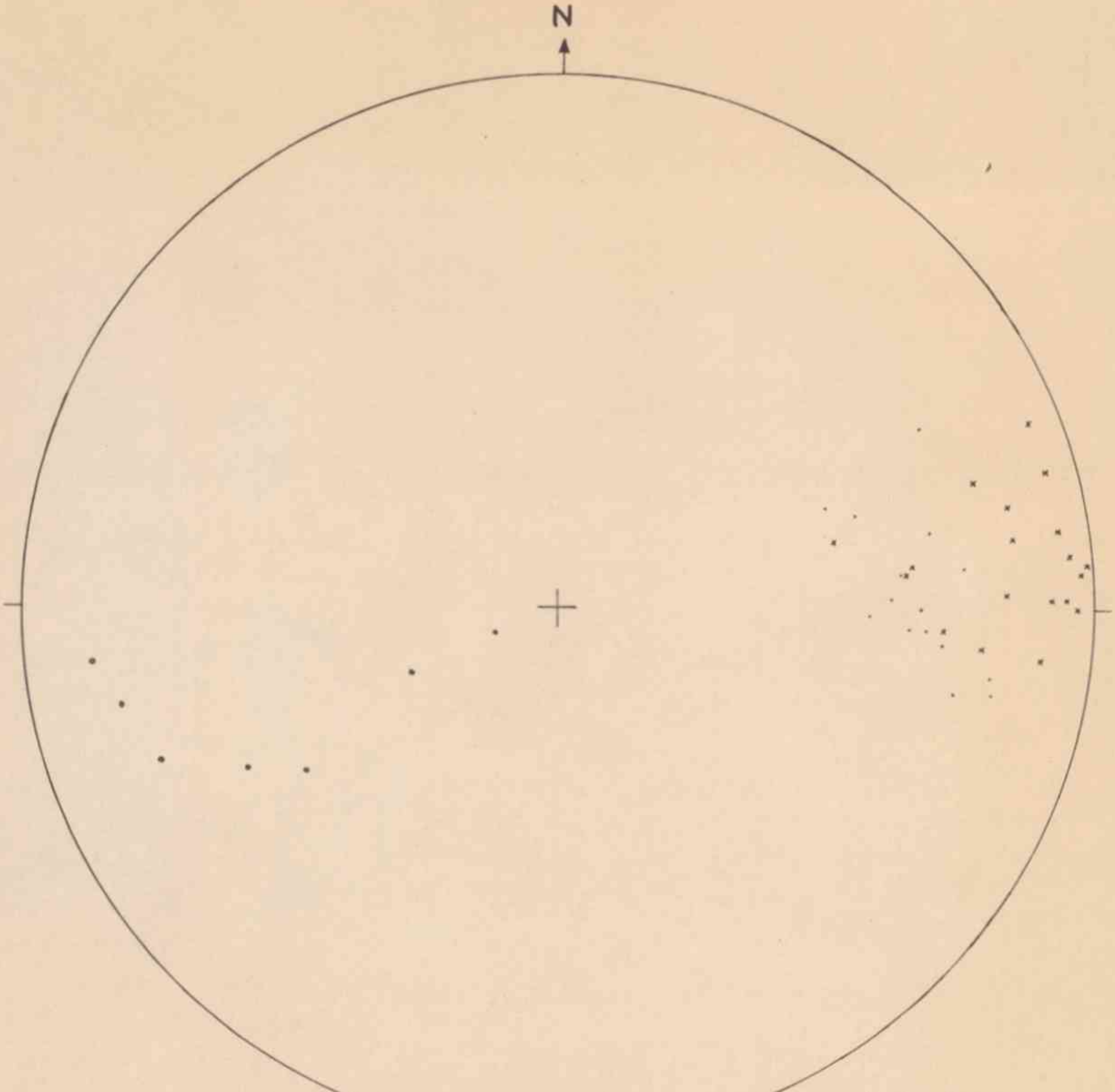


Plate 13. Typical appearance of f_2 crinkle lineations in chlorite schists, 1Km. south of Svorkmo.

Fig. 3.



F_2 CRINKLE LINEATIONS AND KINK BANDS.

Crinkle Lineations.

· Dragset Area

× Rorvandet Road Section

(Projected from the lower hemisphere)

• Schistosity - Kink Band Intersections

Plate 14. Crinkle lineations parallel to the axial direction of f_2 minor folds in chlorite schists.

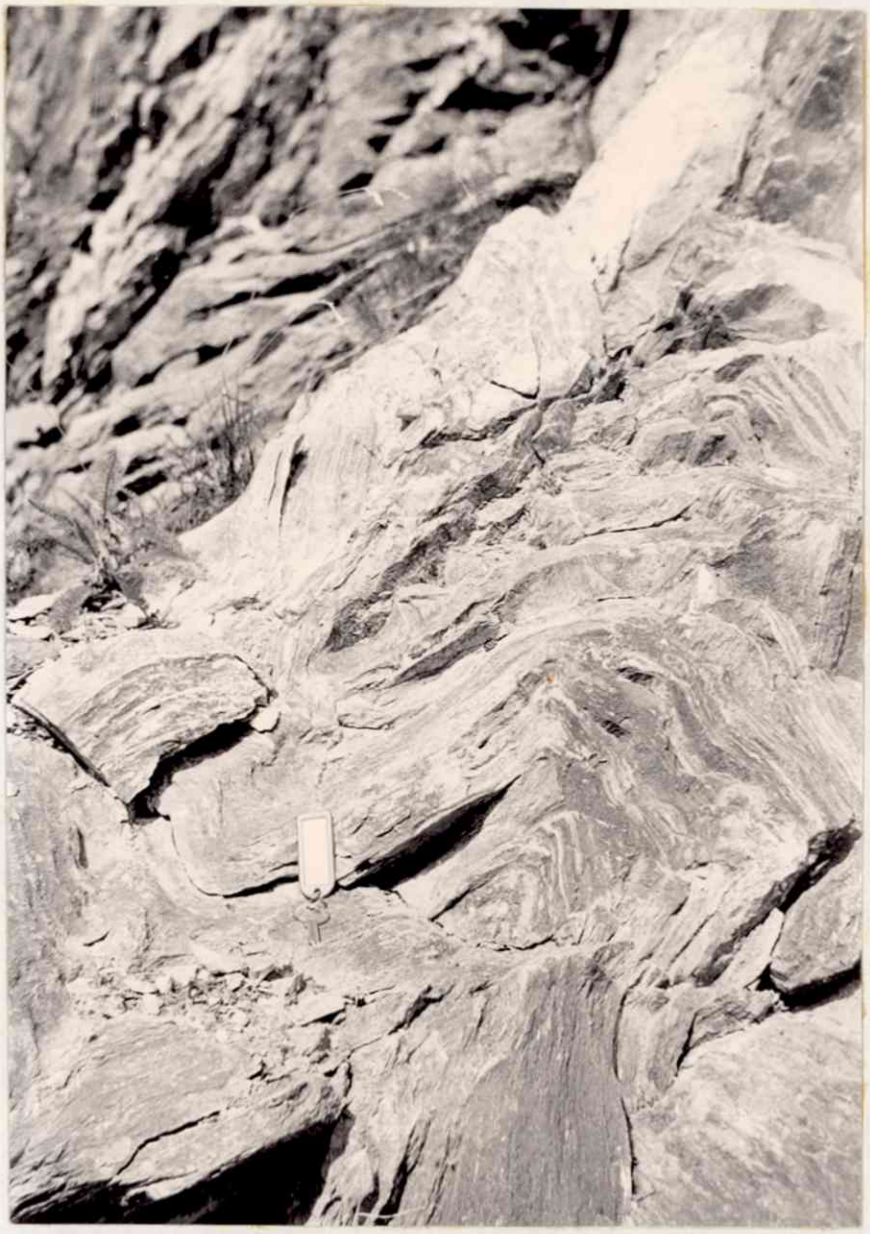
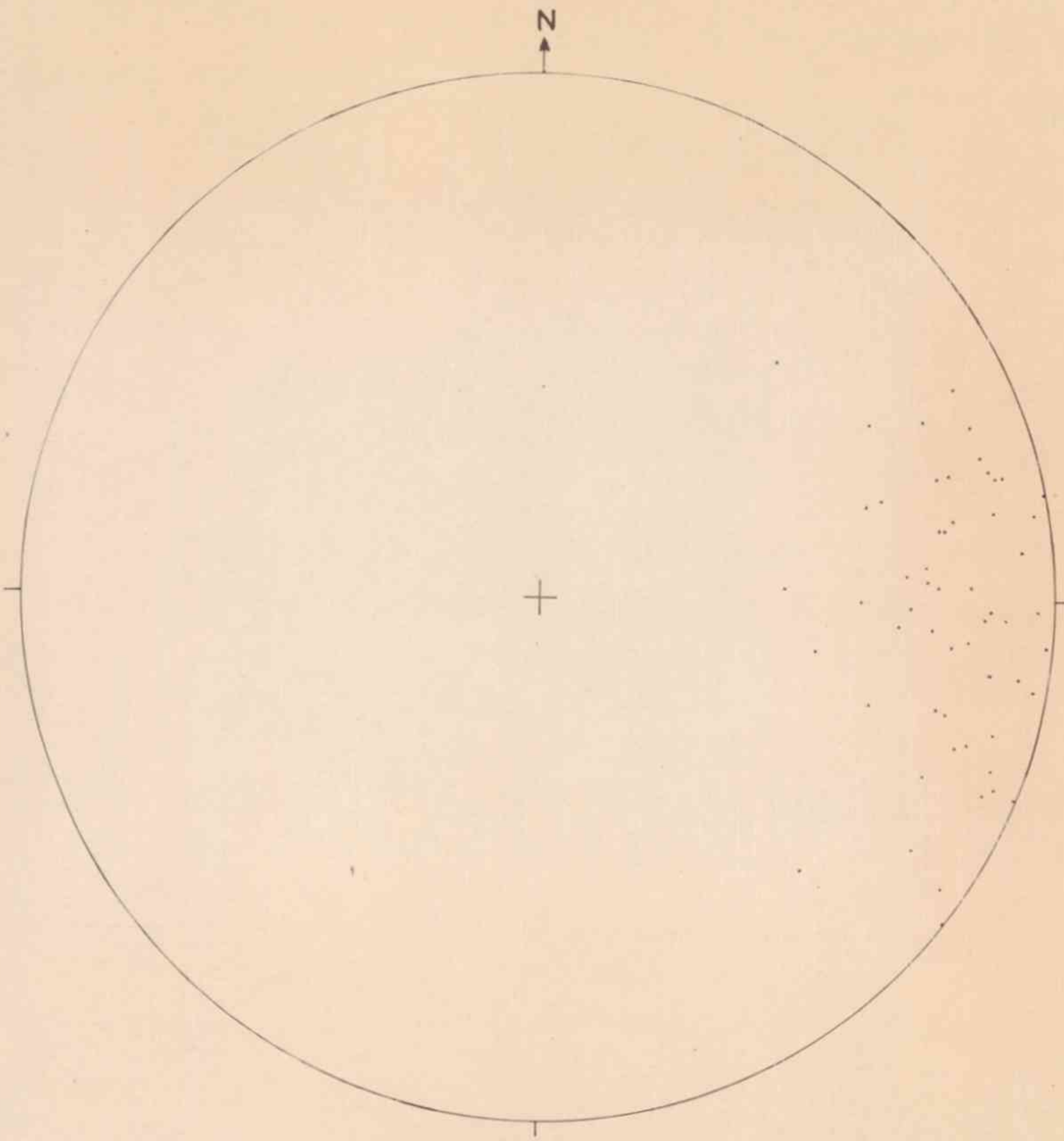


Plate 15. Minor f_2 folds in chlorite schists.

Plate 16. Minor f_2 folds in chlorite schists on the Rorvandet road section. Here the primary banding can be seen to be parallel to the schistosity.

Fig. 4.

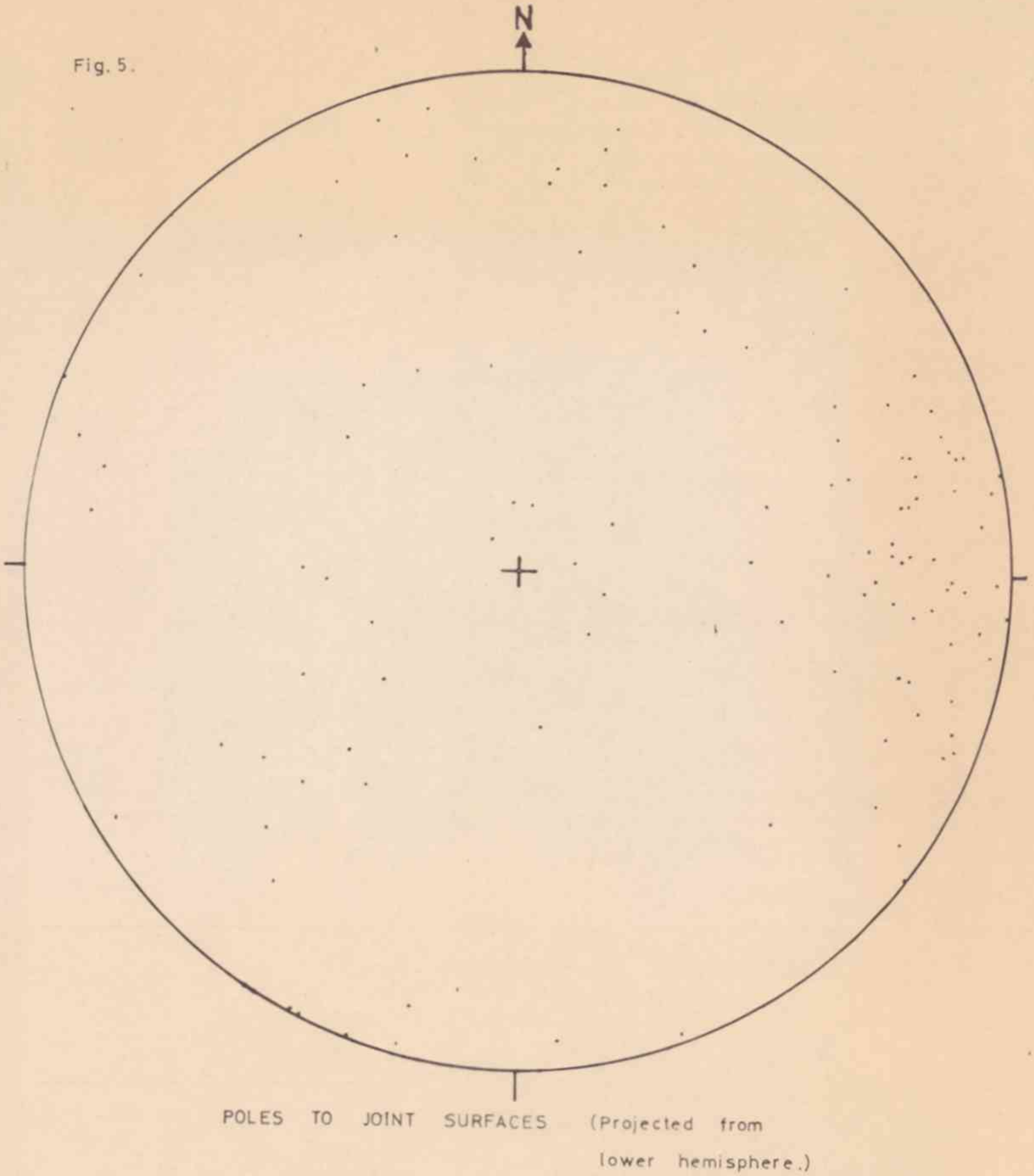


POLES TO THE CROSS JOINT SURFACES

(Projected from the lower hemisphere)

56 Readings.

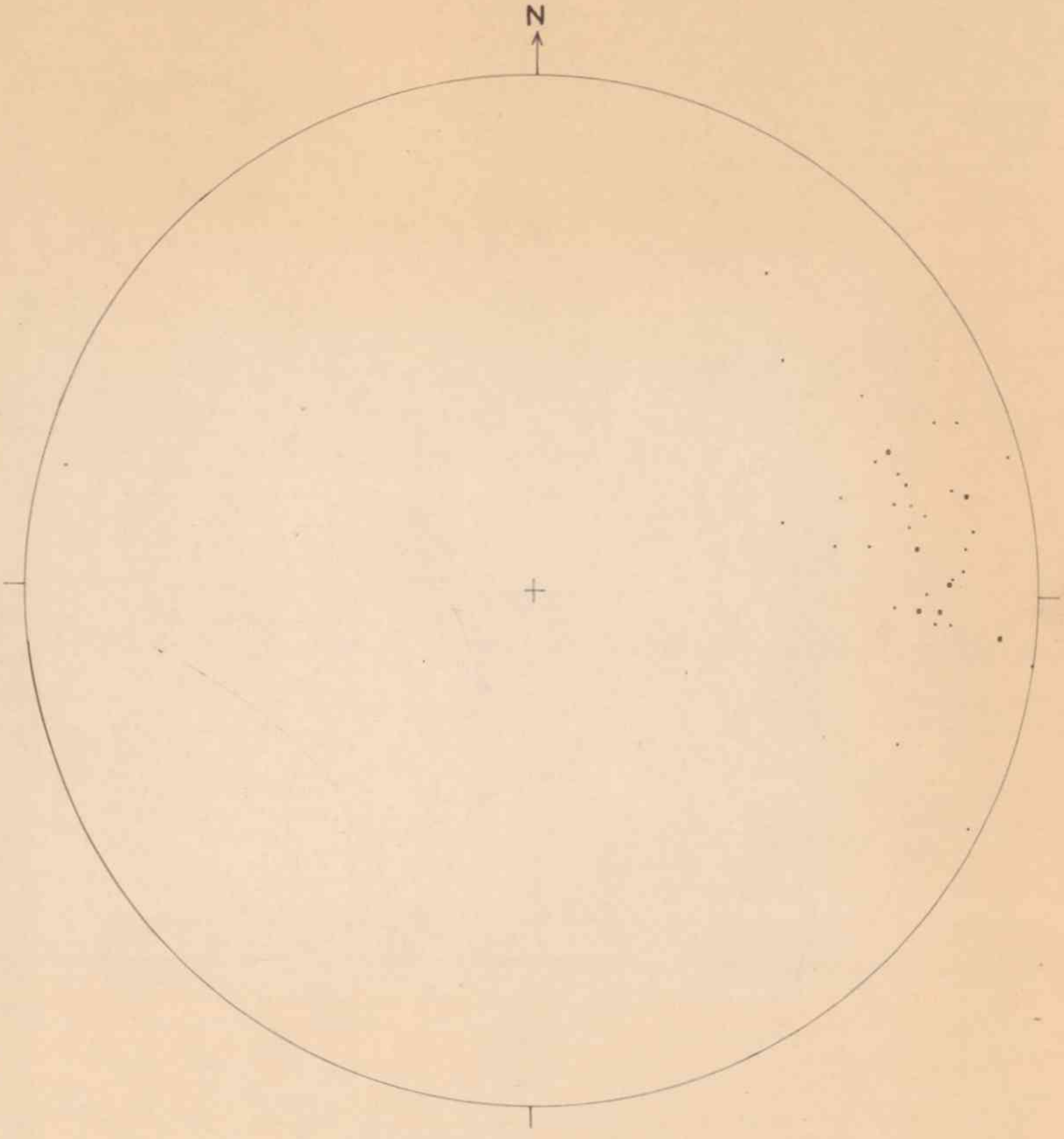
Fig. 5.



POLES TO JOINT SURFACES (Projected from lower hemisphere.)

112 Readings.

Fig. 6.



F. LINEAR STUCTURES.

(Projected from the lower hemisphere)

· Stretch direction

• Plunge direction of minor f. folds

34 Readings.

Fig. 7.

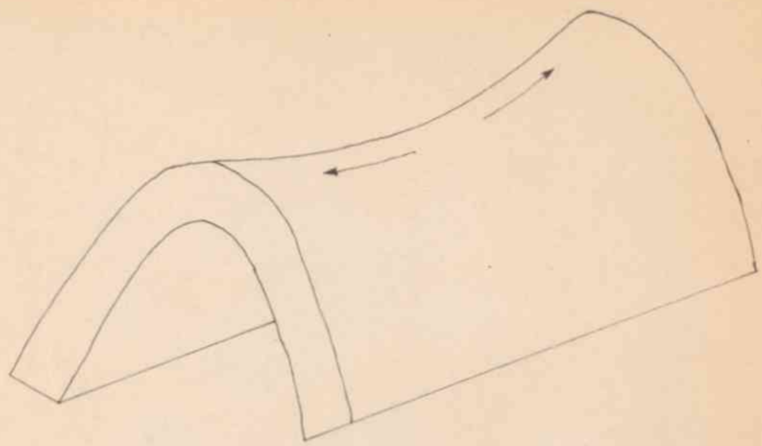


DIAGRAM TO ILLUSTRATE THE PRINCIPLE OF

ANTI CLASTIC BENDING

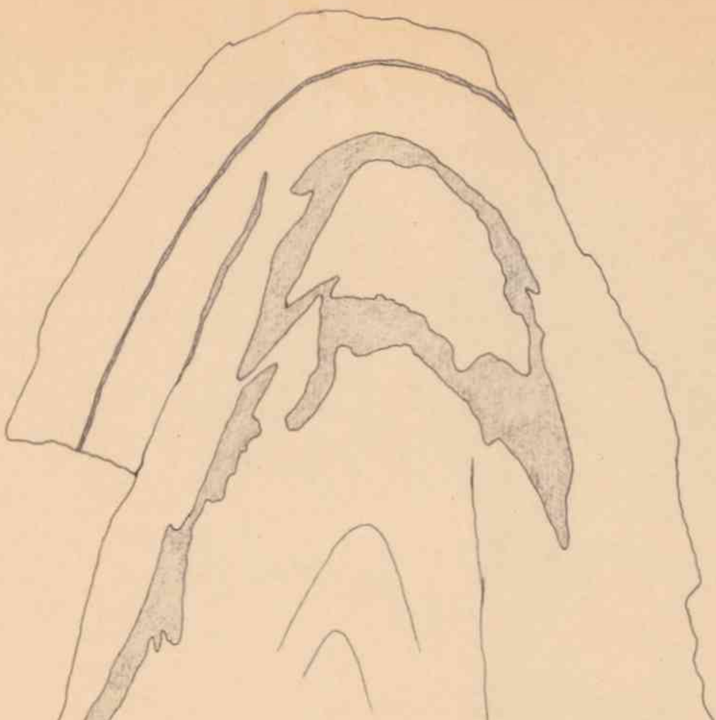


Fig. 9.

f. Fold in a quartz vein refolded by the f_2 deformation.

Plate 17. Small thrust affecting the albite dolerite.

Plate 18. Looking south from Bjortjern along the line of a major fault. The marshy valley, occupied by the fault, contains no outcrops.

Plate 19. Looking north over Bjortjern along the line of a major fault.

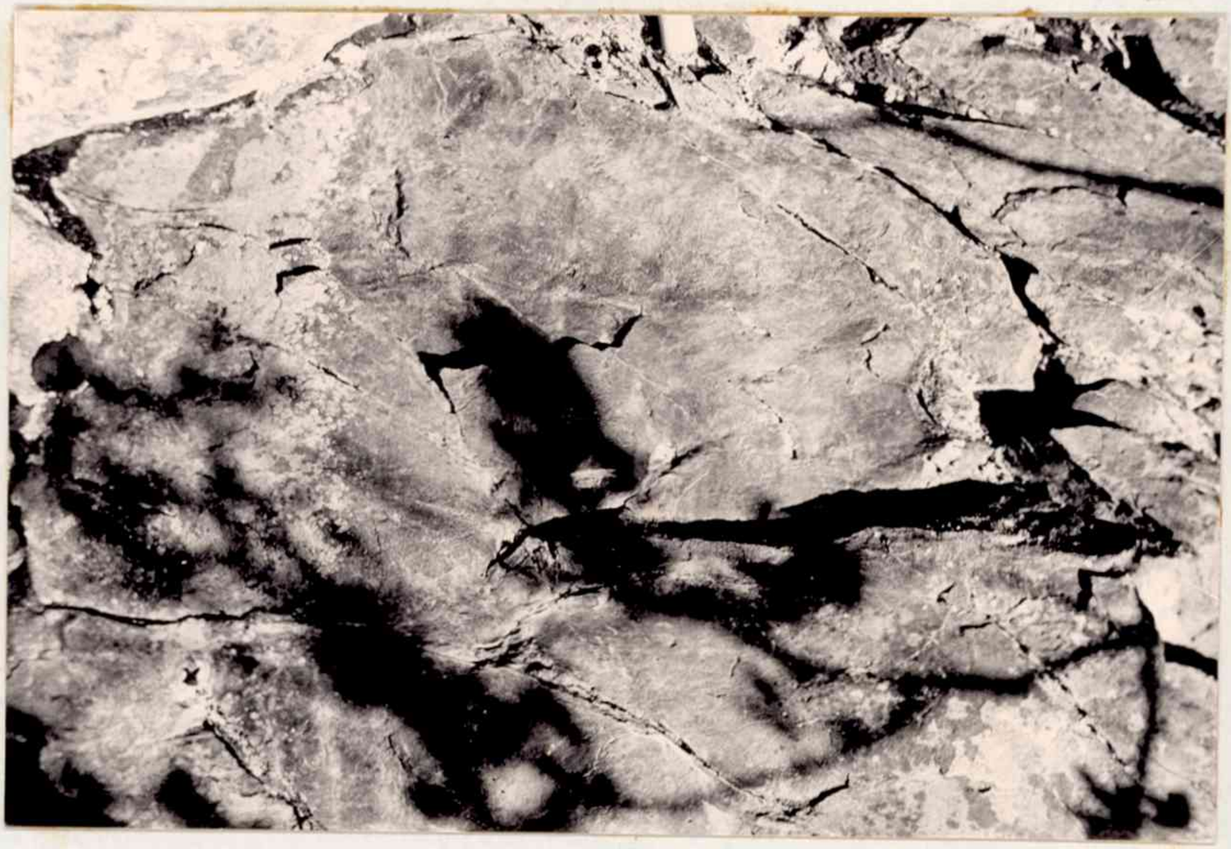


Plate 20. Pillow structures displayed on a well developed cross-joint surface.

Analysis of the Structural Orientation Data

The orientation data obtained from the area mapped by the author was sub-divided into four classes, namely:

(i) Schistosity Planes
(ii) Crinkle lineations on schistosity planes
(iii) Long axes of deformed linear structures (f_1 stretch direction)
(iv) Joint planes

A small number of kink band orientations and f_1 plunge directions were also measured.

Initially, the data collected was plotted as equal area stereographic projections (figs. 2-6). However, in addition to this, the analysis of the data was attempted using the college computer facilities. This work was mainly carried out by Rutter, but the results of the project to date will be discussed, with special reference to the results obtained from the data collected from the Dragset area.

All the orientation data was initially processed using a modified version of a programme devised by Loudon. This programme, written in FORTRAN IV, produced basically the following calculated functions:

(i) The orientation of the principal axes of the distribution of points (either poles to planes or direct orientation of linear structures). The variance of the distribution for all the axes was also calculated.

(ii) The orientation of the axis and apical angle of the best-fit cone to the distribution, that is the cone on which

the data most nearly lies; the variance was again determined.
(iii) A contoured Wulff diagram was produced.

The results obtained emphasised the original supposition that the programme, as it then existed, was far from satisfactory. The Wulff diagram was totally unsatisfactory since it was contoured with reference to the distribution of points on the equatorial plane rather than on the surface of the sphere, and hence the contoured diagram produced was meaningless. The best-fit cone was a function of rather uncertain significance except when considering orientation data from folded layers, as in the case of the schistosity data. Even in this case the orientation of the derived cone bore little relationship to the known structure. When the unimodal distributions were considered, for example, the f_2 crinkle lineation data, the results appeared to be completely random and therefore of very little significance.

The principal axes of the various distributions (fig. 8) on the other hand did show some considerable correlation, both between the various sets of data and also with the structural patterns as determined by classical techniques. It is especially interesting to notice that the divergence of the plunge direction of the major f_2 fold, as shown by the f_2 crinkle lineations, measured from the Dragset area and the Rorvandet road section, is particularly well shown by the difference in the orientations of the major principal axes of the two distributions.

The main problem with the method of analysis of data using the above techniques is the influence of non-random data on the results. There are no facilities for the randomisation of data incorporated into the programme. This is especially important in an area such as the one currently under consideration since the exposure is so poor. In such an area therefore the data tends to be collected at isolated stations, non-randomly situated, and at these stations as much data as is available is collected.

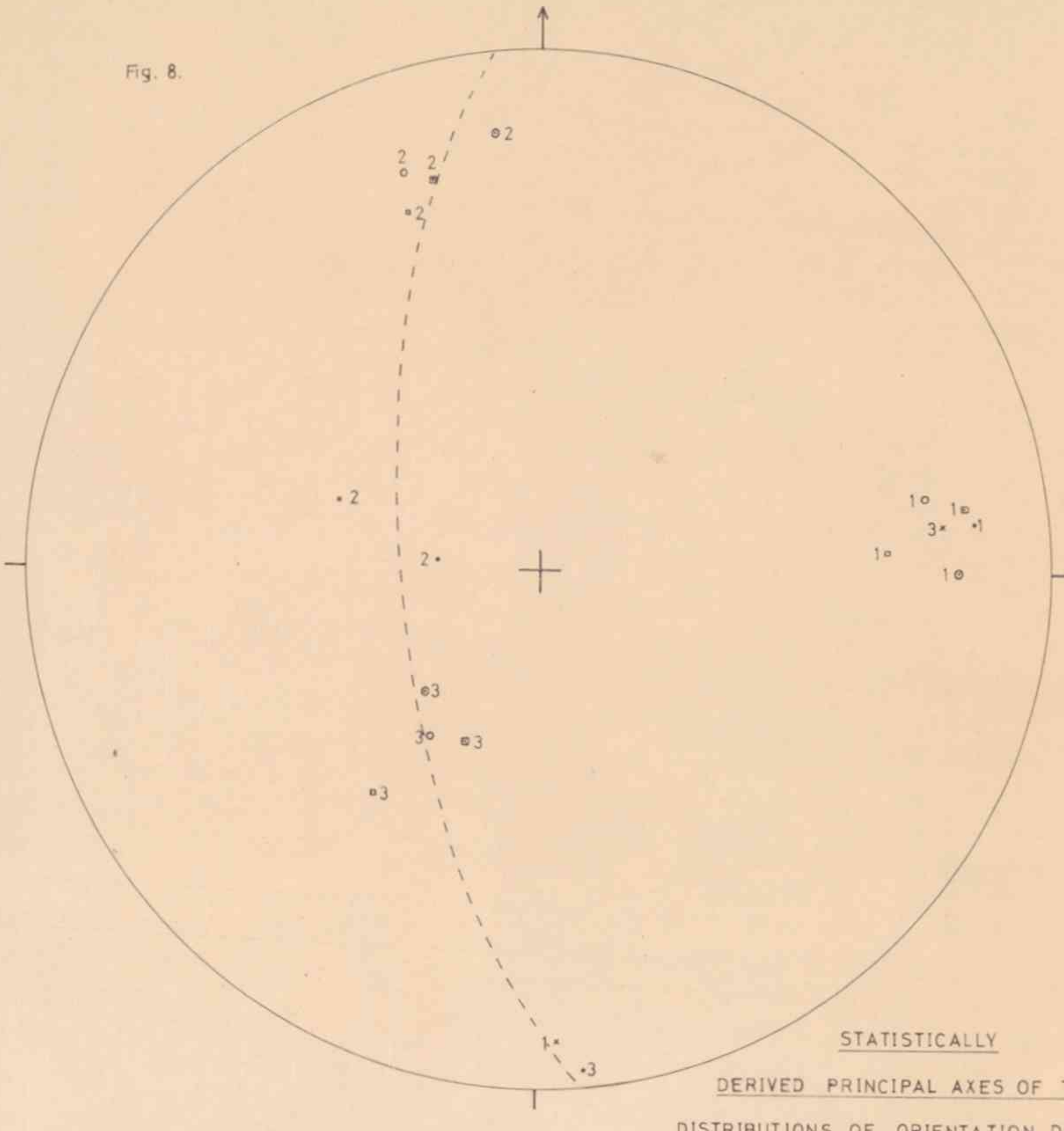
The effects on an analysis, such as has been attempted here, of non-random data are particularly important. Data of this form will tend to produce very distorted results where statistical methods are used.

A good example of the effects of non-random data can be seen in the results obtained for the principal axes of the f_2 crinkle lineation data. Two sets of data were analysed, namely that collected from the Dragset area and that from the Rorvandet road section. When the derived axes are plotted onto a stereographic net, several interesting features can be seen. The major principal axes show good agreement between themselves and also with the known structure; they trend parallel to the f_2 fold axis. The minor and intermediate axes, in contrast, show very little correlation with each other or with the fold geometry; Loudon suggests that the major and minor axes of a distribution such as this should lie in the axial plane of the fold. When it is remembered that both these sets of data were obtained from supposedly the same folded structure it is obvious that some inconsistency exists. The present author suggests that this is a direct consequence of the fact that whereas the data from the Dragset area was collected from both the northern and southern limbs of the synform, the data from the road section came solely from the much steeper northern limb of the structure.

A further problem arises when the question of minor folds is introduced. In the area under consideration the limbs of the major structure, the Lökken Synform, are virtually straight and there are few minor folds on the limbs. However, in an area with a significant amount of minor folding, these minor structures would effectively have to be removed from the data before an analysis of the geometry of the major structure could be undertaken. This operation could be carried out by constructing the inflection surface to the minor folds and analysing this. The problems introduced when there are several orders of minor folds present are obvious.

It is thus clear that the analysis, as initially attempted, is of very limited value. Work is currently being undertaken by Rutter to develop a more satisfactory programme to produce an equal area, contoured stereographic projection. This will have two important characteristics, namely that the data will be randomised and secondly that the diagram will be contoured using a point counting process operative on the surface of the sphere of projection, rather than on the equatorial plane. The randomisation of data is to be initially attempted on a geographical basis. This will involve the inclusion of geographical co-ordinates in all the items of data.

Fig. 8.



- × Poles to schistosity surfaces
- ⊛ Poles to cross joints
- ▪ Poles to joints
- ▫ f_2 crinkle lineations - Dragset area
- • " " - Rorvandet road section
- o f_1 stretch direction

STATISTICALLY DERIVED PRINCIPAL AXES OF THE DISTRIBUTIONS OF ORIENTATION DATA

(The numbers 1,2 and 3 refer to the major, intermediate and minor axes respectively)

Summary and Conclusions

The investigations in the Lökken Area are still in a preliminary state, and much work is still required before the geology of the area is fully understood.

The principal advances made during the 1967 investigations were firstly the establishment of the f_1 axial direction, a problem much discussed by Rutter (1966). The intrusive origin of the albite dolerite is now, in the opinion of the author, clearly established. The schists to the north of Lökken and Dragset are now known to young consistently to the north and therefore they can no longer be regarded as belonging to the Röros Group since they are younger and not older than the Hovin Group of sediments.

The most important problem still requiring investigation is the feasibility of establishing a stratigraphical subdivision for the Stören Group of rocks. The results of the geochemical and petrographic studies being currently undertaken by Dr. W. Skiba may provide a partial answer to this question.

An extension of the area mapped in detail, to the north and west of the Dragset area, is clearly desirable, especially in order to determine the nature of the acid rocks known to exist to the west. The relationship of these rocks to the basic metavolcanics should also be investigated.

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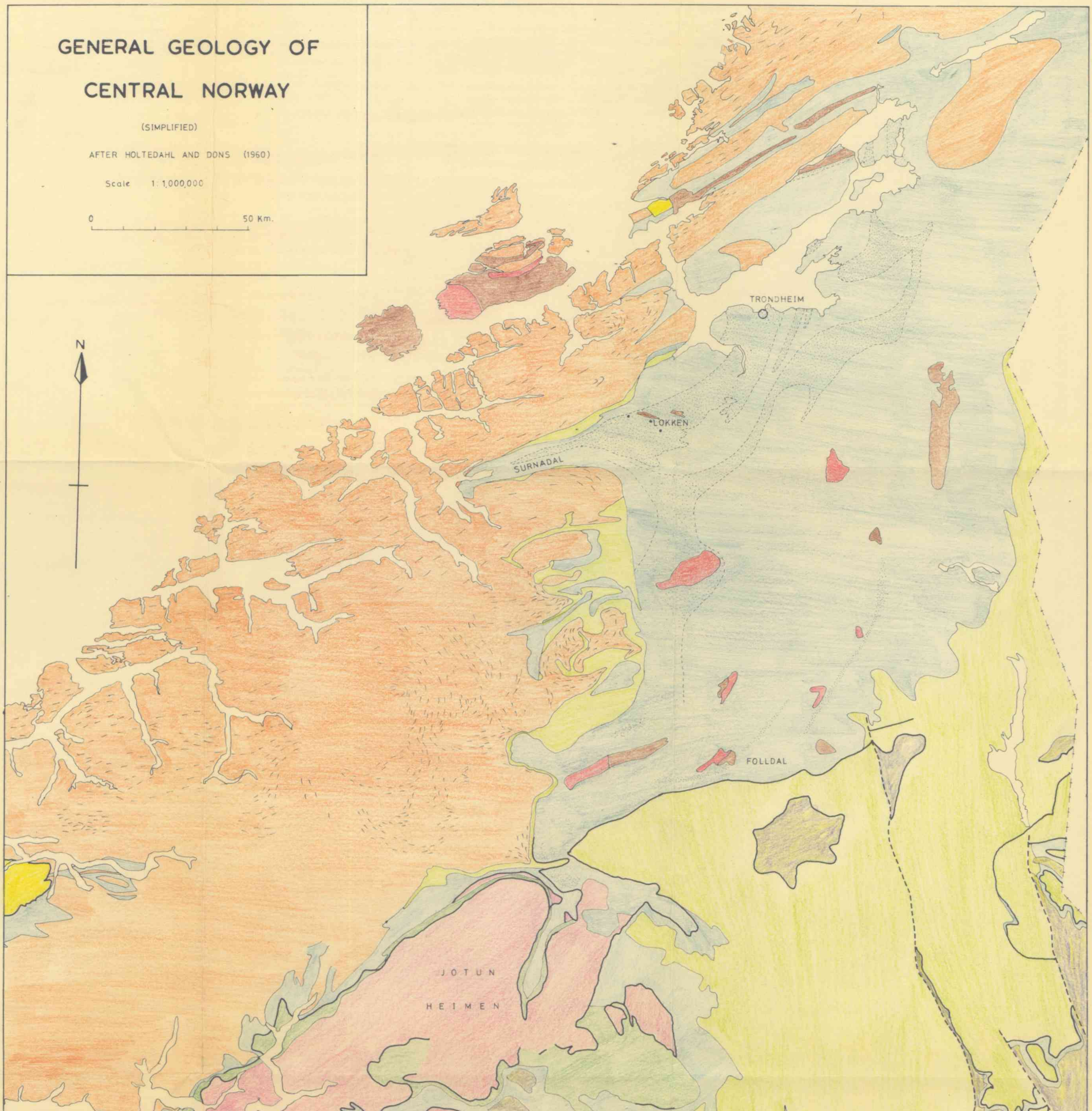
THE GEOLOGY OF THE AREA TO
THE SOUTH-WEST OF
DRAGSET MINE.
N
Magnetic
True North
Hauglitjern
Fjellsletet
Langvandet
Dragset Mine
Dambusletet
Dalatjern
Espassetet
Bjortjern
Rorvandet
Maerratjern
MAP A.
LEGEND
GEOLOGICAL BOUNDARY
INFERRED GEOLOGICAL BOUNDARY
DIP OF SCHISTOSITY
f_1 STRETCH DIRECTION
FAULT
FOLD AXIS (f_2)
DISUSED MINE
MICA SCHIST
CHLORITE SCHIST
FINE GRAINED BASIC METAVOLCANICS
ALBITE DOLERITE
CONGLOMERATE
FRAGMENTARY ACID ROCK
BASIC DYKE
JASPER
SANDSTONE
SCALE
4 inches = 1mile (approx.) 1 : 15,000
0 .25 .5 .75 1.0 Miles
0 .25 .5 .75 1.0 Km.
The base-map was compiled from 1: 15,000 air photographs, hence there is a certain amount of unavoidable distortion.
R. CHAPLOW.
AUGUST 1967.



MAP B.

METASEDIMENTS	EOCAMBRIAN SPARAGMITES	THRUST
BASIC EXTRUSIVES	VALDRES SPARAGMITE (Synorogenic)	FAULT
TRONDHJEMITE	ROCKS IN THRUST MASSES	LITHOLOGICAL BOUNDARY
GABBRO	GNEISS (Structure wholly or in part Caledonian)	PRE EOCAMBRIAN ROCK COMPLEXES (Structure wholly or mainly pre-Caledonian)

Metasediments, basic extrusives, trondhjemite and gabbro: CAMBRO - SILURIAN

SCHEMATIC BLOCK DIAGRAM TO ILLUSTRATE THE STRUCTURE OF THE

LÖKKEN AREA

(NOT TO SCALE)